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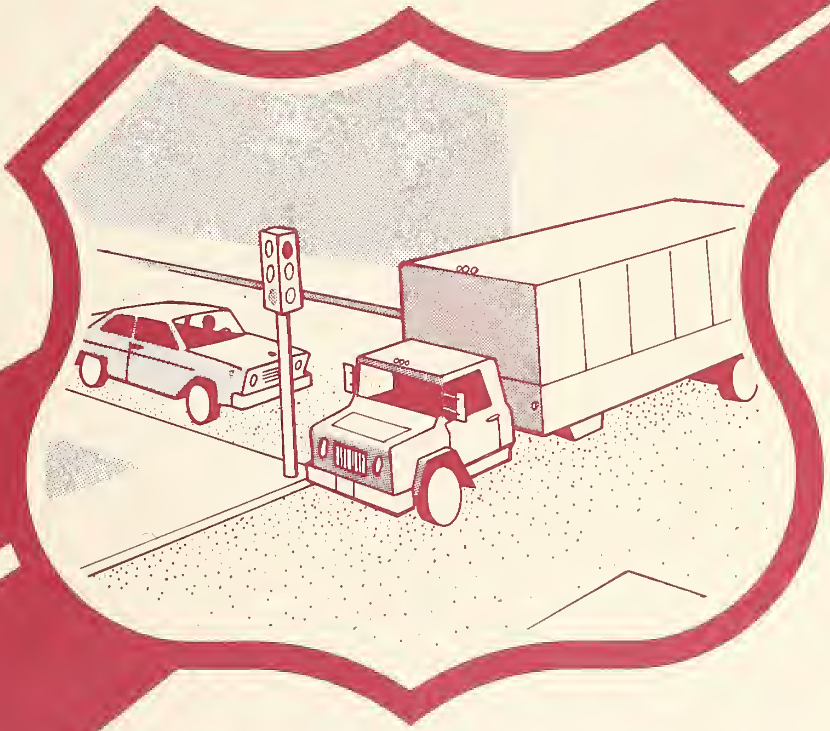
FFECTIVENESS OF ALTERNATIVE SKID REDUCTION MEASURES

Vol. II. Benefit-Cost Model

November 1978

Final Report



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Prepared for
FEDERAL HIGHWAY ADMINISTRATION
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Environmental Division
Washington, D.C. 20590

FOREWORD

This report is part of a final report consisting of an executive summary and four volumes. The executive summary provides a synopsis of the research. Volume I describes the evaluation of accident rate-skid number relationships; Volume II describes the development of the benefit-cost model; Volume III presents the computerized benefit-cost model and instructions for its use; and Volume IV summarizes methods of measuring and achieving macrotexture. It will interest those concerned with pavement surface characteristics and the selection of accident reduction measures.

This research is included in Project 1H, "Skid Accident Reduction" of the Federally Coordinated Program of Research and Development. Mr. George B. Pilkington II is the Project Manager and Mr. Philip Brinkman is the Task Manager.

One copy of this report is being distributed to each FHWA regional office.

Charles F. Scheffey
Director, Office of Research
Federal Highway Administration

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16. Abstract

A computerized benefit-cost model was designed for use by state highway departments in the selection of accident-reduction countermeasures to be applied to investigated sites. Two types of wet-pavement accident reduction countermeasures are in current use: those that increase frictional supply and those that decrease frictional demand. Although this project emphasized countermeasures that influence skid number and wet-pavement accidents, the computerized model treats accidents under both wet- and dry-pavement conditions and, in addition, evaluates costs and benefits for geometric and traffic control countermeasures. Thus, the computerized model is a general purpose tool for the selection of accident countermeasures. The tables supplied with and employed by the model include the published accident reduction percentages for most countermeasures currently employed. The model also includes the relations between wet-pavement accident rates and skid number found in Phase I of this project. In addition, the model includes a novel treatment of highway user costs associated with construction zone activities. It provides as output, cost and benefit data that can be compared and used in budgeting.

17. Key Words

Benefit-cost model
Skidding accidents
Skid number
Computer programs
Wet pavement
Accident countermeasures

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PREFACE

This draft final report was prepared by Midwest Research Institute for the Federal Highway Administration under Contract No. DOT-FH-11-8120. Mr. Charles P. Brinkman of the Office of Research, Federal Highway Administration was the Contract Manager.

The project benefited from the comments and suggestions of several other members of the staff of the Office of Research of FHWA including Mr. Ronald Giguere, Mr. George Pilkington, Ms. Julie Anna Fee, and Mr. Burton Stephens. In addition, the Data Systems Division of FHWA wrote all of the computer programs and made all computer runs for the project. We wish to thank Mr. William Mellott, Ms. Sandy Wallenhorst, Mr. Donald Clausen, and Mr. David Wood of that division for their invaluable contributions. The actual computer programs and program listings are available from FHWA.

We also wish to acknowledge the contributions of 16 state highway and transportation departments and the following individuals who served as principal contacts for the project: Mr. Dave Henry of the California Department of Transportation, Dr. Charles E. Dougan of the Connecticut Department of Transportation, Mr. Thomas I. Bates of the Florida Department of Transportation, Mr. William C. Walters of the Louisiana Department of Highways, Mr. Wilbur Dunphy of the Maine Department of Transportation, Mr. F. Stanley Kinney of the Maryland State Highway Administration, Mr. Francis W. Holden of the Massachusetts Department of Public Works, Mr. Fred Copple of the Michigan Department of State Highways, Mr. Paul Teng of the Mississippi State Highway Department, Mr. Lee Webster of the North Carolina Department of Transportation, Mr. Leon O. Talbert of the Ohio Department of Transportation, Mr. John G. Hopkins, III of the Pennsylvania Department of Transportation, Mr. Robert Fruggiero of the Rhode Island Department of Transportation, Mr. Billy R. Gibson of the South Carolina State Highway Department, Mr. R. V. LeClerc of the Washington State Highway Commission and Mr. John R. O'Leary of the West Virginia Department of Highways. Many other individuals in these agencies provided invaluable assistance which is gratefully acknowledged.

The work reported herein was carried out in the Engineering and Economics and Management Sciences Divisions, under the administrative direction of Dr. William D. Glauz. Mr. Robert R. Blackburn, Manager, Driver and Environmental Group; and Mr. A. D. St. John, Senior Advisor for Analysis, served as principal investigators for the study. Messrs. St. John and Blackburn, together with Mr. Douglas W. Harwood, Associate Traffic Engineer, were co-authors of this volume of the report. Mr. Jerry L. Graham, Associate Traffic Engineer, contributed to Appendix D; and Dr. Stan Soliday (formerly of MRI) contributed to Appendix H. Dr. William D. Glauz, Manager,

Transportation Systems Section, contributed to the organization and editing of this volume of the report. Present and past members of the MRI staff who also contributed indirectly to the work reported include: Mr. Duncan I. Sommerville, Ms. Cathy J. Wilton, and Mr. Patrick J. Heenan.

Approved for:

MIDWEST RESEARCH INSTITUTE

A E Vandegrift

A. E. Vandegrift, Director
Economics and Management
Science Division

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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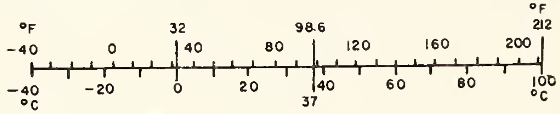
*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



I. INTRODUCTION

Slippery pavements have existed since the advent of the paved highway, but the causes of slipperiness, its measurement, and its influence on traffic accidents were not of great concern before 1950. Although reliable data have been difficult to find, recent research suggests that skidding accidents are increasing rapidly and are reaching proportions that can no longer be ignored. One researcher[1/] has indicated that skidding accidents account for more than one-third of all vehicle accidents in some geographical areas. This trend is undoubtedly a reflection of increased vehicle speeds and traffic volumes.

Each year our highways are used by more vehicles traveling at increased speeds. The increased traffic volumes have reduced the average headway between vehicles, and this reduction, in combination with increased speed, has reduced the time and distance available to the driver to avoid collison circumstances.

More rapid accelerations, higher travel speeds, and more severe braking made possible by modern highway and vehicle designs have raised the frictional demands on the tire-pavement interface. Larger forces are required to keep the vehicle on its intended path. On the other hand, for wet pavements, the frictional capability of the tire-pavement interface decreases with increasing speed. In addition, higher traffic volumes and speeds promote a faster degradation of the frictional capability of the pavement.

The tire-pavement friction level at which skidding is imminent depends mainly on the speed of the vehicle, the cornering path, the magnitude of acceleration or braking, the condition of the tires, and the characteritics of the pavement surface. On wet pavements, speed is the most significant parameter, not only because frictional demand increases with the square of the speed, but also because the skid resistance of the tire-pavement interface decreases with increasing speed.

Skidding accidents constitute a significant traffic safety problem, especially on highways with high vehicle speeds and high traffic volumes. Timely steps should be taken to ensure compatibility between frictional demands and available skid resistance. From the technological standpoint, the skidding accident problem is amenable to solutions that either reduce the frictional demand (such as improved geometric design and wet-weather speed limits), or increase the skid resistance (improved pavement texture and drainage, improved tire design, and more stringent vehicle inspection controls).

The Federal Highway Administration is cognizant of the skidding accident problem and has undertaken a multidirectional safety research effort aimed at the reduction of wet-pavement accidents. The Administration is coordinating complementary research directed at: (1) evaluating the mechanical interaction of the tire-pavement interface, (2) determining the frictional demands of traffic, (3) relating wet-pavement accident rates to available skid resistance, and (4) combining all traffic, engineering, and economic factors in a cost-benefit model. This coordinated approach has promise to successfully achieve its goal of establishing comprehensive skid resistance requirements that can be implemented to compare locations and select appropriate countermeasures subject to funding constraints.

This is the final report on a project (Contract No. DOT-FH-11-8120) concerned with the third and fourth of the above goals of the FHWA approach to the wet-pavement accident problem. The project consists of two phases, corresponding to the two major objectives of the project:

1. To develop the relationships between pavement skid number and wet-pavement accidents for a variety of highway and traffic conditions (Phase I).

2. To define and evaluate, on a cost-effectiveness basis, a range of alternative solutions to the problem of maintaining the frictional requirements of drivers during wet weather (Phase II).

The final report is divided into four volumes. Volume I describes the work conducted and results obtained under Phase I; Volume II pertains to the work performed under Phase II; and Volume III is a user manual describing the benefit-cost model developed under Phase II and the instructions for the model use by state highway departments. Volume IV is a guide to the subject of pavement macrotexture. It discusses the importance of pavement macrotexture in reducing skidding accidents and describes the methods of measuring pavement macrotexture, and the techniques for providing macrotexture in new pavements and restoring macrotexture in existing pavements. Volume IV also applies a simplified version of the benefit-cost approach presented in Volumes II and III to the evaluation of alternative pavement macrotexture improvements.

The results reported in this volume cover the Phase II activities. This phase involved the identification of potential effective countermeasures for wet-pavement accidents, the development of a comprehensive computerized benefit-cost model to evaluate those countermeasures, the development of a computerized system to support the benefit-cost model, the assembly of a data base for the model, and the applied demonstration of the model.

The Federal Highway Administration's Data Systems Division performed all of the computer programming for the benefit-cost model and its support system, the data system management, and the program execution. Midwest Research Institute provided FHWA with program specifications, logic descriptions, and flow diagrams at various levels of detail. The actual programs and program listings are available from FHWA.

This volume is organized in the following manner. Section II describes the scope and application of the benefit-cost model. The computerized support system for the model is discussed in Section III. An overview of the computerized benefit-cost model is described in Section IV. This is followed by a description in Section V of the major components and concerns of the model. Section VI presents a discussion of accident rates: their relationship to skid number and associated variables (drawn from the results of Phase I); their association with geometric and traffic control measures; and the way the relations are incorporated in the model. The subscript ranges dealing with the countermeasures employed by the computerized benefit-cost model and its support system are given in Section VII. A summary of the model's input requirements and output format are discussed in Sections VIII and IX, respectively. Section X presents examples of the benefit-cost model while tests of the model are given in Section XI. The conclusions of the Phase II activity are presented in Section XII followed by the recommendations in Section XIII.

Eight appendices are given at the end of this report. These present discussions of the following topics: potential countermeasures for skidding accidents, skid numbers, accident severities and costs, added user costs during construction, flow diagrams for the computer programs, subroutine hierarchy, the symbol names used in the computer programs, and means of controlling skidding by influencing driver behavior.

II. BENEFIT-COST MODEL SCOPE AND APPLICATION

The computerized benefit-cost model is designed for use by state highway departments in the selection of accident-reduction countermeasures to be applied to investigated sites. Two types of wet-pavement accident reduction countermeasures are in current use: those that increase frictional supply and those that decrease frictional demand. Although this project has emphasized countermeasures that influence skid number and wet-pavement accidents, the computerized model treats accidents under both wet- and dry-pavement conditions and, in addition, evaluates costs and benefits for geometric and traffic control countermeasures. In fact, it is essential for the model to treat both types of countermeasures since they must be evaluated in competition with one another for selection of countermeasures with the most favorable benefit/cost ratios. Thus, the computerized model is a general purpose tool for the selection of accident countermeasures. The tables supplied with and employed by the model include the published accident reduction percentages for most countermeasures currently employed. The model also includes the relations between wet-pavement accident rates and skid number found in Phase I of this project.

The model makes use of engineering judgement by examining only those countermeasures for a site that the user specifies with input data. The specified countermeasures are examined, first, in comparison to the "as is" or "as planned" conditions for the site. Those countermeasures found to be economically feasible are then compared with one another to identify the countermeasure with the best benefit/cost ratio. Printed output is provided for the economic feasibility results and for the subsequent comparisons that are frequently described as project formulation. The printed output contains the important economic and safety variables useful for decision making. In this regard it is recognized that the model deals individually with each potential site for countermeasure application. Ultimately, in budgeting, sites must be considered in competition for the best distribution of countermeasure funds. The model does not deal explicitly with this site-to-site competition, but instead provides printed results for each site that can be compared and used in budgeting.

The computerized model currently examines countermeasures individually. The logical organization of the model could be extended to evaluate multiple countermeasure options, but it does not presently have the capability to evaluate the benefit-cost ratio for such combinations of countermeasures.

In the development of the computerized model, emphasis has been placed on compatibility with normal highway department practices and on accurate quantification of accident and economic consequences. The model provides accurate evaluations of accident and economic aspects in cases where: (1) a prior decision has been made to modify the analyzed site; (2) future resurfacing or rebuilding will influence the life of countermeasures; (3) right-of-way must be acquired for a countermeasure; (4) the ADT will change drastically in the future due to the addition of continuing segments or parallel facilities; or (5) the facility will be abandoned in a future year. Current practice most frequently employs approximations or engineering and economic judgement to account for the above factors; the computerized model handles them explicitly.

The computerized benefit-cost model utilizes auxiliary data files that supply standard values for such items as countermeasure costs and accident reductions, and the distributions of accident severities and accident costs. A support system of a computer program provides procedures for a state highway department to incorporate and update the values of these items. In addition, the user in the highway department is given the option of supplying overriding values in individual calculations.

Figure 1 shows the elements involved when the benefit-cost model is executed. The details of that program are presented beginning with Section IV of this report. The support system and file maintenance are described first, in Section III.

The remainder of this report concentrates on the work performed by MRI, but recognizes the coordinated efforts of FHWA's Data Systems Division, which performed all of the computer programming, data system management, and program execution. The coordination was accomplished by MRI's provision of program specifications, logic descriptions, and flow diagrams at various levels of detail. For each program or segment, the level of detail was selected to leave maximum latitude for the programming and data system management, while simultaneously providing great detail where necessary to ensure incorporation of the correct logic. Examples of the extremes are found in the very general specification of the support system, as contrasted with the detailed specification of logic for certain routines in the benefit-cost computer program. This report reflects the specifications provided. The actual programs and program listings are available from FHWA.

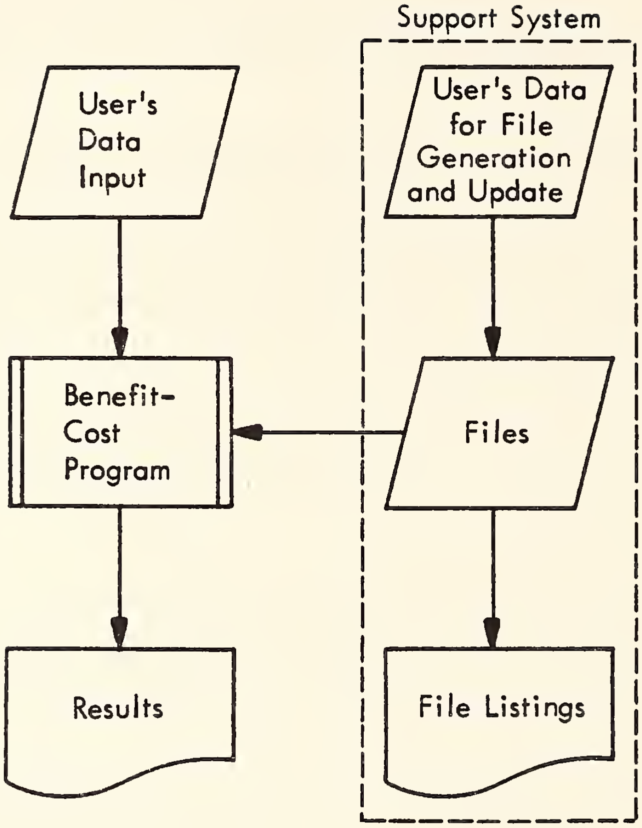


Figure 1 - Benefit-Cost Program Operation

III. SUPPORT SYSTEM

The functions and capabilities of the support system are:

1. The support system is used to update cost data files.

2. The support system provides a printed listing of the updated and replaced cost data.

3. The printed listing is useable to manually verify the new cost data and, subsequently, provide a document for record and reference.

4. Cost data in the federally demonstrated system can be specific for individual states, and for cost centers within states. (When the system is used in a state highway department, cost data can be specific for each regional cost center of the state.)

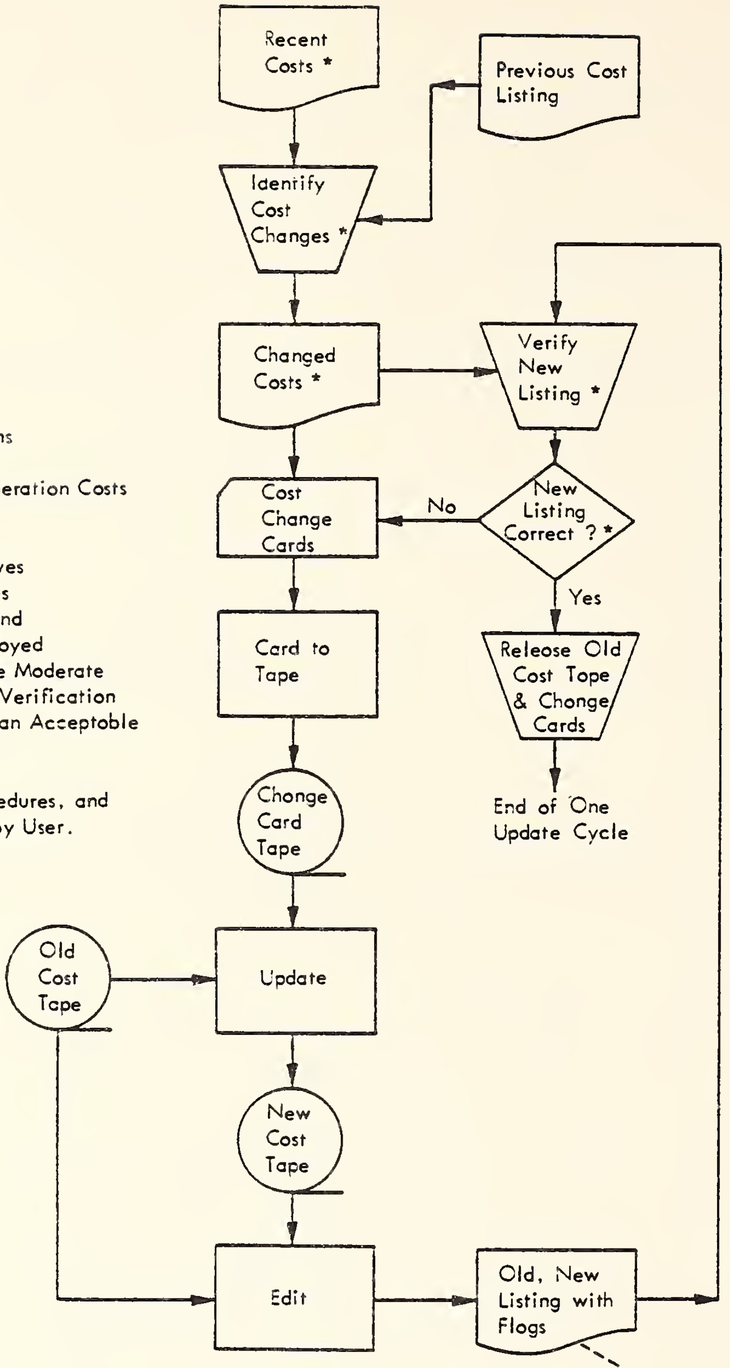
5. The system provides the correct cost data files to the benefit-cost program in response to the input on state and region associated with each case analyzed.

Figure 2 shows the process of updating (maintaining) the support system cost files. The process includes the provision of new cost data for the files, the incorporation of these new data in the files, the generation of listings of the files and changes, and manual verification of the changes.

Three other capabilities for the support system may have utility in continued application but were not needed in the development activities of this project. These three capabilities are described below.

1. A permanent file sequenced by case number could be generated, where a case is one analysis of one or more alternatives. (A case number should be assigned even if the analysis is terminated after the preliminary computations in the benefit-cost model indicate that significant accident savings cannot be achieved. A case number should not be assigned when analysis is terminated due to incorrect or incomplete input data.) The system should transmit the next case number to the benefit-cost program. The sequential file should include the case number, and numerical codes for the date of analysis, the type of facility, the feature, i.e., intersection, curve or section, the climatological coefficients (up to three) and the location information which includes the state, the state subdivision, and the milepost limits.

2. The case file could be updated with decision and implementation data. The decision information is the date of decision and the selected countermeasure type (including none). The implementation date is the date when the countermeasure is completed and in use.



Files are for:
- Capital Costs
- Accident Reductions
- Accident Types
- Maintenance & Operation Costs
- User Costs
- Accident Costs
- Normal Service Lives
- Net Salvage Values
- Costs of Removal and
- Interest Rates Employed

Files are Expected to be Moderate in Size so that Manual Verification of New Values will be an Acceptable Procedure.

* Documentation, Procedures, and Decisions Performed by User.

Listing Contains Abbreviated Names
Changed Values are Flagged.
Changes Exceeding Threshold % are Double Flagged.
Accepted Version is Retained by User to Document Values in Use and to Prepare Next Update.

Figure 2 - Maintenance of Support System

3. The third capability would delete unused countermeasures, and/or add new countermeasures in limited numbers. Printed output should document the revisions and dates of revisions.

IV. THE BENEFIT-COST MODEL--AN OVERVIEW

The benefit-cost model was designed to be implemented as a computer program. Thus, unless specifically stated otherwise, references to the model apply equally to the program, and vice-versa.

This overview begins with a discussion of the fundamental attributes of the model. Next, the basic two-step concept utilized in examining alternative countermeasures to wet-pavement accidents is discussed. Finally, the overall flow diagram is presented and described briefly. Further details are reserved for Section V, subsequent sections, and the appendices.

A. Model Attributes

The main attributes of the model (and the supporting system) are set by the envisioned applications. The model will be applied to evaluate countermeasures intended primarily to provide, as benefits, reduced costs of wet-pavement accidents. However, the model deals with total accidents and includes the capability to calculate benefits and costs for accident countermeasures in general.

The model (and the computer program) are intended for use by state highway department personnel. Consequently, emphasis is placed on employment of information likely available, and compatibility with procedures employed by state highway departments.

The attributes and capabilities of the benefit-cost model are listed below.

1. The model is compatible with typical highway department organization and procedures. (Primarily, this means accounting for the consequences of prior decisions on abandonment, resurfacing, or rebuilding where the decisions were motivated mainly by factors other than wet-pavement accidents.)

2. The model provides both economic analysis and project formulation analysis. Economic analysis evaluates the economic feasibility of alternatives, and project formulation compares those alternatives found to be economically feasible.

3. The model is organized to facilitate the analysis of conventional countermeasures with minimal user input.

4. The program accepts unconventional countermeasures with user-oriented input.

5. The program accepts a list of specified countermeasures for analysis.

6. There are two conventional methodologies for comparing alternatives with unequal lives. Each method has value. The program uses one method as a standard and provides an option for the user to request the other.

7. The program provides a convenient way for the user to modify, for individual cases, the costs of accidents and values of time. (These costs and values are frequently questioned.)

8. The computer program employs modular blocks to facilitate changes to the logic and to numerical values.

9. The computer program combined with other system elements is able to run several problems in succession.

10. The computer program provides printed output for each case that can be used in planning and budgeting decisions, and subsequently as a permanent record of the results of analysis.

B. Two Steps--Economic Feasibility and Project Formulation

The principal measure of effectiveness used in the model is the benefit/cost ratio. Using this ratio, an analysis is performed in two steps. In the first step each countermeasure is compared with a base condition, which is the "as is" or "as planned" condition for the facility. Countermeasures that provide a B/C ratio of one or more are judged to be economically feasible. If more than one countermeasure is judged economically feasible, a second step is undertaken to identify the best of the feasible countermeasures.

The second step is called project formulation or incremental analysis. The first operation for this step is to rank the economically feasible countermeasures in order of increasing capital costs. Then, the first-ranked countermeasure (lowest capital cost) is taken as the base and the next ranked countermeasure is taken as a challenger. If the resulting (incremental) B/C ratio is equal to or greater than one, the challenger is accepted and becomes the base countermeasure in a calculation with the next ranked countermeasure. On the other hand, if the ratio is less than one, the challenger is discarded, and the base countermeasure is retained for comparison with the next ranked challenger. This process continues until each economically feasible countermeasure has challenged and has either been accepted or discarded.

There are three special aspects of the above sequence that influence the operation of the benefit-cost program. First, the project formulation calculations are needed only if more than one countermeasure is found to be economically feasible. The test for this possibility is made in the main program.

Second, it is recognized that the program does not make final decisions for a highway department. This is especially true in the project formulation calculations where, although the results always lead to the countermeasure yielding the most benefit per capital cost dollar, the sequence progresses through countermeasures with successively larger capital costs. Since, realistically, budget constraints are usually present, a final decision rests with the management and administration of the highway department. The cost-benefit program provides information useful in reaching that decision. Therefore, each calculation of both the economic analysis and the project formulation (if needed) are printed as an aid in decision making and subsequent review.

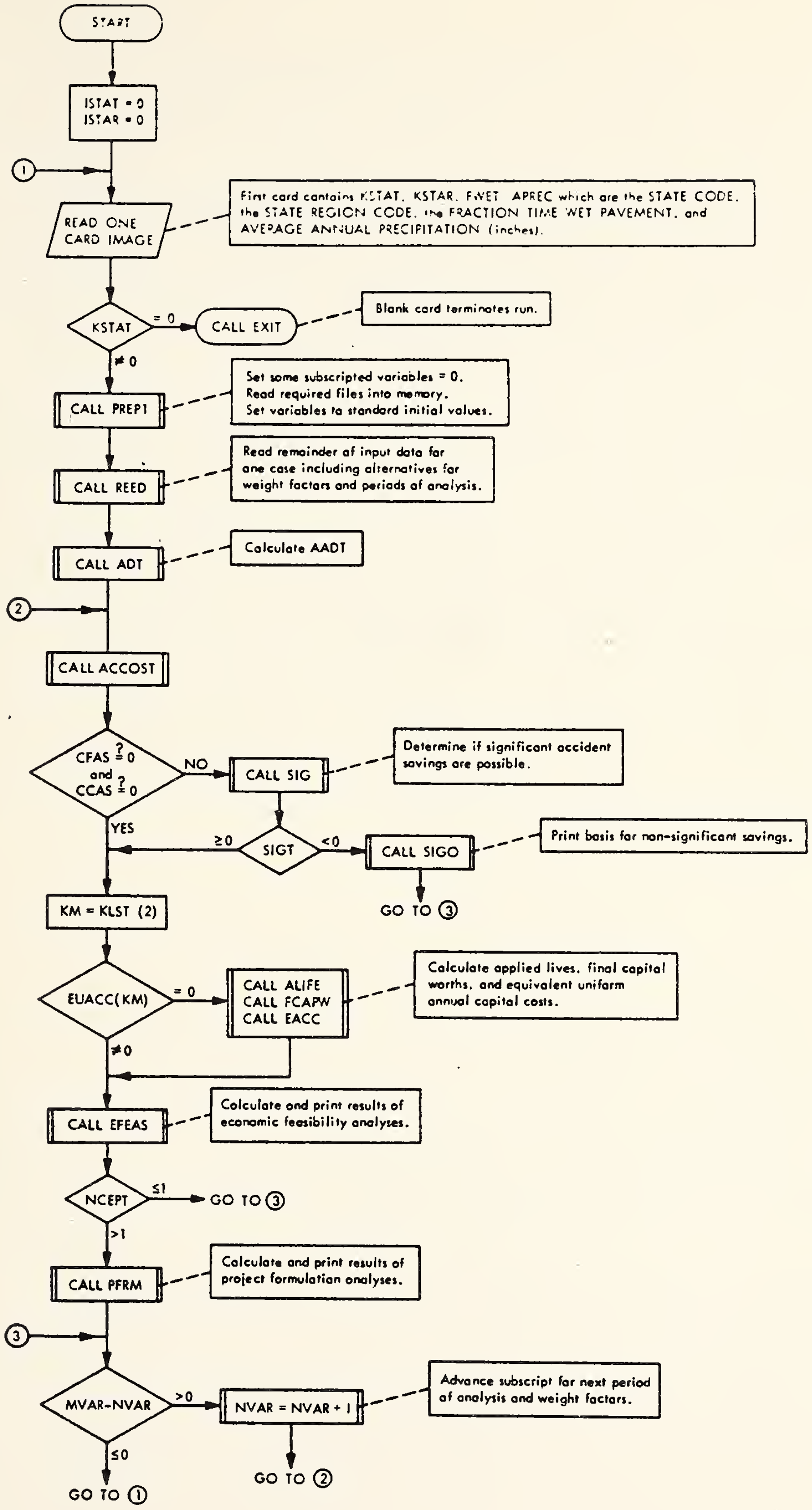
Third, it is apparent that the form of the calculations and the results are similar in the two steps--economic analysis and project formulation. The same headings and print formats are thus appropriate for both. The only difference is in the main heading. Also, each calculation involves three elements: a base condition, either a countermeasure or a challenger, and differences reflected in the benefit/cost ratio (and other measures). These three elements lend themselves to three lines of printed output for each calculation.

C. Overall Program Logic

The major routines of the benefit-cost computer program are shown in the flow diagram of Figure 3. The notes in the figure describe the general course of computations.

One pass through the logic diagrammed in Figure 3 completes the benefit-cost analyses of all requested countermeasures at one highway site or section. The early routines read input information, obtain data from the support system files, and initialize variables. The next routines calculate for each requested countermeasure its applied life, its final capital worth, and capital costs at the highway site analyzed.

Routine EFEAS conducts the economic feasibility analysis by comparing the consequences with each requested countermeasure against the consequences with the "as is" or "as planned" conditions at the site. All the results are printed, and each countermeasure that provides a benefit/cost ratio of one or more is accepted as economically feasible. If two or more countermeasures are economically feasible the program continues by employing routine PFRM.



First card contains KSTAT, KSTAR, FWET, APREC which are the STATE CODE, the STATE REGION CODE, the FRACTION TIME WET PAVEMENT, and AVERAGE ANNUAL PRECIPITATION (inches).

Blank card terminates run.

Set some subscripted variables = 0.
Read required files into memory.
Set variables to standard initial values.

Read remainder of input data for one case including alternatives for weight factors and periods of analysis.

Calculate AADT

Determine if significant accident savings are possible.

Print basis for non-significant savings.

Calculate applied lives, final capital worths, and equivalent uniform annual capital costs.

Calculate and print results of economic feasibility analyses.

Calculate and print results of project formulation analyses.

Advance subscript for next period of analysis and weight factors.

Figure 3 - Benefit-Cost Flow Diagram

Routine PFRM conducts the project formulation analysis by testing one economically feasible countermeasure against another. The procedure starts with the countermeasure that has the smallest capital cost and challenges that countermeasure with the countermeasure with the next higher cost. Challenging countermeasures that exhibit an incremental benefit/cost ratio greater than one are accepted and used in subsequent incremental analyses against next higher cost countermeasures. The results of all incremental analyses are printed. This concludes the benefit-cost analysis of the highway site with the user-specified countermeasures.

The test on MVAR-NVAR is part of an option to repeat the analyses at the same site, using the same countermeasures but with a different period of analysis and/or different accident cost values.

The computer model contains some logical elements that are not very well-defined by currently available data. These elements have been given analytical forms that permit the use of best estimates and are also convenient for making sensitivity tests.

V. MAJOR COMPONENTS AND CONCERNS OF THE MODEL

In this section are discussed the main aspects of the beneift-cost model, other than accident probabilities and their relationships to various countermeasures, which are the subject of Section VI.

The computer program terminology is described in Section A, and the philosophy behind and equation for the benefit/cost ratio are given in Section B. Several features of an economic nature, means of defining and apportioning costs, etc., are presented in Sections C through G. The effect of prior decisions to rebuild or otherwise modify a highway facility, and how the program handles these decisions are presented in Section H. The subject of the cost of right-of-way is treated in Section I. Section J explains how the model provides flexibility in dealing with particular costs of a controversial nature--the costs of accidents, including injuries and fatalities, and the value of time and delays. The means of treating accidents of various severities, and the file data furnished relative thereto, are described in Section K. User costs imposed by construction associated with countermeasure implementation are discussed in Section L. Maintenance and operating expenses associated with the countermeasures are in Section M, and traffic volume estimates and their change in time are described in Section N. Finally, a review of the relationships between skid number and factors such as material properties, traffic volume, and aging is given in Section O.

A. Terminology

Many of the following portions of this and subsequent sections deal with details of the computer program logic. Reference to the flow diagrams in Appendix E (and the actual program listings) is simplified by utilizing the same symbols and names in the discussion. The symbols and names, which are suggestive of their functions, are generally defined where first used in the discussion. Appendix F contains a complete listing (with definitions) of these names.

The program, written in FORTRAN IV, makes extensive use of subscripted variables. They are identified in the program and in the discussion as a symbol name followed by the subscript in parenthesis. Thus, FCW(KM) is the final capital worth of countermeasure KM, where KM identifies a specific countermeasure of a series being examined. The notation FCW( ) is used to signify the entire array of values of final capital worths.

B. Benefit/Cost Ratio

The ratio of benefits to costs is used as the main measure of countermeasure effectiveness. In general, it is defined as the fraction (using non-computer terminology):

$$B/C = \frac{AC_b - AC_c + MO_b - MO_c + UC_b - UC_c}{CC_c - CC_b},$$

where AC = Accident costs

MO = Maintenance and operating costs

UC = User costs

CC = Capital costs, and

subscript b indicates the base condition, while

subscript c indicates the condition with countermeasure.

In the program formulation step, the subscript b refers to the base countermeasure and c refers to the challenging countermeasure.

Experts are not in agreement on the location in the fraction of the MO and UC terms. We follow Winfrey,[73/] placing the terms in the numerator. With this form the denominator contains capital costs exclusively.

C. Compound Interest Forms

The compound interest forms used in the model logic are based on year-end cash flows. That is, all payments, receipts, and benefits are treated as though they occurred at the end of each year. The discount factor $1/(1+i)^n$ is used to obtain the present worth of a single amount n periods (years) in the future with interest rate i (a decimal, such as 0.06). The capital recovery factor is $[i\ (1+i)^n]/[(1+i)^n - 1]$. It is used to convert a present capital worth (when the countermeasure is installed prior to the beginning of the first year) to the equivalent uniform annual capital cost over a life of n years at interest rate i .

Winfrey has coined the word, vestcharge, to describe the interest rate employed in economic analyses of investments in public works. The symbol name V has been employed in the flow diagrams for this interest rate. The symbol name V1 is employed for V + 1.0 .

In the computer program a standard rate VS is obtained from the data files and V is set equal to VS in subroutine PREPI. The program user may provide another value for V to be read in subroutine REED.

D. Period of Analysis and Applied Life

Several problems arise in selecting a period of analysis and making an equitable comparison between alternatives that have different lives. However, before this question can be addressed, it is necessary to examine the practical aspects that determine the life of a countermeasure.

According to normal economic practice, the life of a countermeasure would be the number of years that the principal capital cost items would last while serving their intended purpose. However, in the present application, it is necessary to recognize that additional factors may limit this time period. As a simple example, consider a highway section that is scheduled for resurfacing at the end of 2 years, to restore the riding qualities and weather-resisting properties. A surface treatment with a normal service life of 3 years could be applied now to improve skid number. However, the skid number improvement would be realized for a maximum of only 2 years. The phrase "applied life" has been adopted here to describe the period that the countermeasure capital item(s) will actually be employed for their intended purpose. Applied life may equal but not exceed normal service life. In this example, the applied life is 2 years.

There are several types of future actions and normal expectations that may reduce the applied life of a countermeasure below its normal service life. They are:

- Plans to resurface in a future year (applied life is normal remaining life of present surface course).

- Plans to rebuild in a future year (applied life is normal remaining life of present facility).

- Plans to abandon facility in a future year (applied life is normal remaining period of operation of facility).

All countermeasures are not equally vulnerable to future actions. A code has been devised to describe vulnerabilities, and logic has been devised to determine applied lives. The logic is applied in subroutine ALIFE where the applied life of each countermeasure is calculated for the site under study. However, the program user may specify the applied life of individual countermeasures and override the file values and logic normally used. To provide this option the subscripted values of applied life, LAF( ), are set equal to zero in subroutine PREPI; values supplied by the program user are read in subroutine REED; and subroutine ALIFE tests the LAF( ) values individually for user input before employing normal computational logic. Similar options are provided the program user for other quantities described subsequently, such as final capital worth and capital cost.

In the analyses for economic feasibility each countermeasure is compared with the base condition--the "as is" or "as planned" condition. In these analyses the periods of analysis are taken as the applied life of the countermeasure. The applied life includes the effects of future plans for the facility.

When two alternatives with unequal applied lives are compared a period of analysis must be chosen and employed. Winfrey recommends a period of analysis equal to the shorter of the two lives. He argues that predictions for the near term are more certain and that for the shorter-lived alternate, another option is possible at the end of the period. Economists seem to prefer the longer period and assume that the shorter-lived alternate recycles.

In the present application there does not appear to be a "right" choice for period of analysis. The longer-lived alternate may exhibit enhanced benefits in the future due to traffic growth and the characteristics of the countermeasure. If the shorter period is chosen, the longer-lived alternate may be unfairly penalized. If the longer period is chosen, it may be unfair or unrealistic to assume that the shorter-lived alternate goes through additional cycles. We meet this problem by taking the longer life as the standard period of analysis but provide the user with the option to request a second analysis that employs the shorter of the applied lives. Even if the analyses produce different results they will provide useful information for management decision making which can consider the confidence in projections used and the indicated burdens on current and future budgets.

The symbol JPER( ) is used in subroutine PFRM as a code for selection of period of analysis. A code value of 1 selects the shorter period; 2 selects the longer period. The default value JPER(1) = 2 is set in subroutine PREPI. That subroutine also initializes MVAR, the largest subscript to be employed for JPER( ), to the value, 1. The value of JPER(1) can be altered in subroutine REED, or the range of subscripts, MVAR, can be increased to include other options for both JPER( ) and the weight factors for costs described in Section E which also must be defined for the subscripts 1 to MVAR.

The subscripts for JPER( ) and the cost-weight factors are part of an option to calculate benefit/cost ratios under more than one set of cost or time period estimates. When the subscript is given a range MVAR greater than one (in input), MVAR separate sets of calculations are made for the same site and set of countermeasures. Each calculation set employs the JPER( ) and cost-weight factors supplied by the user for the associated subscript.

E. Forms for Capital Costs and Benefits

Authorities in economic analysis agree that in a comparison between two alternatives the period analyzed (period of analysis) should be the same for both alternatives. However, in order to provide an equitable valuation of each alternative, the concept of equal periods is frequently carried out implicitly rather than explicitly. The calculation of capital costs is an example which is now described.

An equitable valuation of capital costs for a countermeasure considers:

- The initial capital outlay, COI
- The applied life, n
- The final capital worth, FCW, at the end of applied life, and
- The vestcharge or interest rate, i.

The capital costs can be expressed in terms of their present worth, PWCC, by

$$PWCC = COI - FCW \cdot PW_{in}^{*}$$

where $PW_{in} = 1/(1+i)^n$, the present worth discount factor for n years at rate i . (i is expressed as a decimal, not as a percentage).

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* This form assumes that the capital outlay COI is made immediately preceding the beginning of the first year. This assumption is employed in all logic.

The capital costs can also be expressed on an annual basis as the equivalent uniform annual capital cost, EUACC , where

$$\mathrm{EUACC} = \mathrm{PWCC} \cdot \mathrm{CR}_{in}$$

and $\mathrm{CR}_{in} = i\,(1+i)^n/[(1+i)^n - 1]$ is the capital recovery factor for n years at interest rate i .

Now, consider a period of analysis, m , which is shorter than the applied life n .* The equivalent uniform annual capital cost is still a fair valuation of capital costs since it has been placed on a per-year basis. However, the present worth of capital costs for the reduced period needs to be adjusted to reflect the remaining capital worth at the end of the shorter period, m . After the adjustment the valuations are equivalent; they differ only in form and units. It is important to note that with the shorter period of analysis neither of the forms for capital costs contains much information about the initial capital outlay.

Because EUACC is unchanged by the period of analysis, the model employs the equivalent uniform annual capital costs. Consequently, the benefit/cost ratio is formed as EUAB/EUACC , where EUAB is the equivalent uniform annual benefit. Benefits are defined as (accident savings) - (increases in user costs) - (increases in maintenance and operating expenses), as noted in Section B.

It is seen from the above that capital costs are adjusted implicitly to periods shorter than applied life. In fact, the capital costs have an intrinsic cost/year character. One form, equivalent uniform annual capital cost, does not change with the period analyzed. One might be tempted to treat benefits in a similar fashion so that the equivalent uniform annual benefits for each alternative would be independent of the analysis period. But the benefits may be greater or smaller in later years compared with earlier years. Thus, when equivalent uniform annual benefits are evaluated for compared alternatives over different periods, the comparison may not be equitable. Consequently, the benefits must be evaluated for compared alternatives over equal time periods.

In summary, the equivalent uniform annual capital cost provides equitable valuations of capital costs even when applied lives of compared alternatives are not equal. But, to be equitable and comparable, benefits must be evaluated over the same time periods.

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* This would be done if the countermeasure is being compared with another having a shorter applied life.

F. Capital Outlays

As indicated previously, when capital costs are transformed into equivalent uniform annual capital costs, the information about initial capital outlays is obscured. Therefore, initial capital outlays and applied lives appear in the printed output from the computer program. The capital outlay is calculated in subroutine EACC as the product of UN(KM), the number of units required, and either CAPC(KM) or SCAPC(KM), where CAPC(KM) is the capital cost per unit for countermeasure KM provided from the support system data file and SCAPC(KM) is an overriding value that can be supplied by the program user in subroutine REED.

G. Final Capital Worth

The capital cost items for a countermeasure have a final capital worth when the applied life ends. In the simplest case the final capital worth is the typical net salvage value. In other cases additional applied life may be realized by removing and reinstalling the capital cost items. Their final capital worth in the initial application is, of course, reduced by the cost for removal. Some capital items may have a final capital worth in place. An example is a surface course that is covered by resurfacing. The covered course may have structural value that persists and contributes to the life or load-bearing capabilities of the pavement.

A code is employed in subroutine FCAPW to calculate final capital worth. The value of this code, TLR(KM), which is supplied from the data file for countermeasure KM, contains integer and fractional parts (Base 10). If the countermeasure capital items are disturbed by rebuilding, but not by resurfacing, the integer part of TLR(KM) is 1, and the fractional part is the fraction of the <u>then</u> capital value that can be recovered during rebuilding. Again, that value is exclusive of the cost of removal, which is CR(KM) per unit capital item. If the countermeasure capital items are disturbed by resurfacing, the integer part of TLR(KM) is 2 and the fractional part is the fraction of the <u>then</u> capital value that can be recovered during resurfacing exclusive of costs of removal. When the integer part of TLR(KM) is 2 and the facility is rebuilt, it is assumed that the final capital worth is equal to the net salvage value.

The final capital worth for each unit of countermeasure KM, FCW(KM), can be entered by the program user as input read in subroutine REED. If the applied life LAF(KM) is directly supplied by the user for KM, then a non-zero value of FCW(KM) <u>must</u> also be supplied in input. If the final capital worth is zero or negligible, that fact should be indicated by inputing the smallest positive quantity permitted by format.

H. Prior Decisions

The model treats prior decisions in a simple and explicit way. (Here, a prior decision is a decision affecting the highway facility or traffic control that has been made but not carried out.) The base condition takes the facility as it will be after prior decisions are carried out. This is similar to the attitude generally employed in benefit-cost analysis, where prior actions and their costs and consequences are irrelevant. However, in this case, there is an opportunity to evaluate the comparative costs and benefits of alternatives that will implement the prior decisions and simultaneously reduce the likelihood of wet-pavement skidding accidents.

Frequently the prior decision will be to resurface or rebuild. In these cases, the initial base condition must be the "as planned" condition. The condition includes the new surface course. If alternative surface courses are considered as countermeasures, the alternatives should be charged capital costs only for the difference between the previously selected course and the alternative. (The difference in capital costs includes the effects of differences in service life, if any.)

KLST( ) is a list of subscripts (pointers), identifying the specific countermeasures contained in the support system file that are to be compared in an analysis. The initial base condition is always assigned subscript 1, and KLST(1) = 1. Therefore, the prior decisions can be incorporated in the description of the base condition as a part of input data for the case. It should be recognized that the capital costs for the base case will be employed only when an alternate surface course is considered as a countermeasure. If countermeasures other than alternate surface courses are considered, the capital cost for the base case will not be employed.

Capital costs for the "as is" or "as planned" surface course may be employed whenever an alternate surface course is considered as a countermeasure. When there has been a prior decision to resurface (still subject to modification), the logic for economic feasibility charges the alternate surface course for its cost but also charges the "as planned" base condition for its planned capital costs. If the alternate surface course is found to be economically feasible, its capital cost is subsequently reduced to reflect the capital outlay already "sunk" in the "as planned" condition. This adjustment, which accounts for both costs and applied lives, is necessary so that the alternate surface course can compete fairly in project formulation against other countermeasures that do not involve surface courses.

Capital costs for the "as is" surface course <u>may</u> enter the economic feasibility calculation when a surface course countermeasure is considered. The "as is" capital costs enter only when the life of the countermeasure course will extend beyond the future year when the "as is" course would be replaced. In this case a fair comparison requires an account of the future outlay required for the "as is" base case. The model logic discounts the "as is" future outlay and distributes it over the period extending from the present to the end of the replacement life. There is no effect on the project formuation calculations.

To implement the required logic the countermeasures that are surface courses are given the smallest subscripts (after subscript 1). If the largest subscript for surface courses is KSM, this value will be used in the tests to determine if capital costs in the base condition should be included. The test is part of subroutine BOC.

I. Right-of-Way Costs

Only a few countermeasures may involve ROW (Right-of-Way) costs. Examples are: added turn lanes at intersections or driveways, added continuous turn lanes in retail commercial areas, and reconstructed horizontal curves. Countermeasures which involve ROW costs require additional input from the program user and use of additional logic in the computer program.

Each countermeasure that may require ROW costs has two subscripts associated with it. The smallest of the two subscripts is employed to identify the countermeasure and the costs, lives, etc. associated with the non-ROW aspects of the countermeasure. The larger subscript for countermeasure KM is equal to KM + K2, ana is used for the ROW costs, life or amortization period, and final capital worth supplied by the program user. The data items required are:

LIFC(KM + K2), the ROW life or amortization period;

SCAPC(KM + K2), the capital cost per unit of ROW;

UN(KM + K2), the number of ROW units required; and

FCW(KM + K2), the final capital worth per ROW unit after LIFC(KM + K2) years.

The logic in subroutine EACC calculates the equivalent uniform annual capital costs for (KM) and (KM + K2) separately and then combines them under subscript KM for the total equivalent uniform annual capital cost EUACC(KM). The capital outlay is also combined under KM as CØL(KM). The logic in subroutine EACC also requires that:

KM2 = Smallest subscript of countermeasures which may require ROW.

KM3 = The next subscript value above the range for countermeasures which may require ROW.

The above logic provides an equitable inclusion of costs for ROW that usually has a much longer life than other countermeasure capital items. The logic can also be employed for equitable costing in circumstances such as described in the following paragraphs.

Countermeasures that require ROW may be considered for facilities that are scheduled for rebuilding in a future year. However, the countermeasure may require that part of the future ROW be acquired in advance of the time it would be needed for overall rebuilding. In this case, the input data should include the total acquisition costs per unit of needed ROW as SCAPC (KM + K2). However, the life LAF(KM + K2) should be supplied as the time (years) until normal acquisition, and final capital worth FCW(KM + K2) should be input equal to SCAPC(KM + K2). As a result the countermeasure will be charged a cost equal to the interest for the advanced capital outlay, only.

In this circumstance the countermeasure construction may be compatible with the future rebuilding plans, so that a part of the countermeasure construction costs will be recovered during scheduled rebuilding. Input to the computer program, FCW(KM), can specify a final capital worth after a life LAF(KM) (also input to the program) that reflects the amount recovered and time until recovery.

In case ROW is available, no charge for ROW costs should be made against the countermeasure. That is, SCAPC(KM + K2) = 0. (CAPC(KM + K2) is always left equal to zero.) Likewise, if ROW is obtained for future rebuilding on a schedule that makes it available earlier for the countermeasure, the capital costs for ROW should be zero.

J. Weight Factors for Certain Costs

Two types of cost and benefit data have strong influences on economic analyses of highways and traffic, yet are very controversial. They are the costs of injury and fatal accidents, and the value of time. The program employs standard values and costs in the data files, but also gives the user the option of assigning separate weight factors for each of the above in input. The weight factors can thus be used in sensitivity tests or to apply extra emphasis to the accident reduction aspects of countermeasures. The standard cost values are described more fully in Sections K and L.

The weight factor symbols are: FPD( ) for property damage only, FIA( ) for injury accident, FFA( ) for fatal accident, and FUTC( ) for value of highway users' time. The default values (subscript 1) are all 1.0 and are set in subroutine PREPI. These values may be superceded by input read in REED or the range of subscripts MVAR can be increased to correspond to additional sets of factors supplied in input.

K. Accident Severities and Costs

Accident severities are classified as property damage only, injury, and fatal. The user of the computerized model is given the option of supplying the baseline year (year before implementation of countermeasure) accidents by severity or total only. If the baseline year accidents are provided by severity, that distribution is employed for the precountermeasure condition. If only the total is supplied, default distributions are supplied by the model. The default distributions of severities are distinct for area type-highway type combinations. The area types are rural and urban; the highway types are two-lane uncontrolled access, multilane uncontrolled access, and multilane controlled access. The default distributions currently in the model are based on data from the states of California, Michigan, and Washington. The numerics are presented in Appendix C.

The cost per accident in each of the severity classes is formed as the product of the cost per unit involved and the average number of units per accident in the severity class. For property-damage-only accidents, the unit is a vehicle. For injury accidents, the unit is an injured person; in fatal accidents, the unit is a fatally-injured person. In the injury and fatal classes the property damage costs are included in the costs given.

The assembly of standard accident costs for each severity is performed outside the model as the products indicated above. The values initially supplied with the model are presented in Appendix C. The standard costs per accident by severity are part of the data files accessed by the computer program. If the model user specifies weight factors for accident costs (other than the 1.0 defalut values), those factors are applied in the computer program.

When the model treats accident reductions, the injury and fatal severities are combined. This approach is consistent with the accident reduction data and the small sample problems that attend fatal accident reductions. It should, however, be recognized that the <u>initial</u> (precountermeasure) distribution employs injury and fatal severities separately so that accident costs in the baseline and in the countermeasure conditions correctly reflect the accident costs at the site analyzed.

L. User Costs

The user costs incorporated in the model are those arising from construction associated with the countermeasures.* The costs are due to increased delay (vehicle-hours/year) and excess fuel consumed (gallons/year) in years when construction occurs. The costs are incurred in the baseline year (prior to countermeasure implementation) and periodically in future years if the countermeasure is replaced in the period analyzed. The cost per vehicle-hour and per gallon of fuel is part of the data file, so that current values will be available from updated files.

An analysis was performed to evaluate the added delays and increased fuel consumption associated with the countermeasures. The results are incorporated in the benefit-cost model in convenient analytical forms. The delays considered are those due to queuing and to depressed speeds at the construction zone. The added fuel consumptions considered are due to idling in queues, speed change cycles, and depressed speeds. The delays and the fuel consumption depend on the area type, the normal highway configuration, the construction zone configuration, the zone length, the ADT, the daily schedule for construction zone configuration, and the number of calendar days required.

The basis for delay and fuel consumption calculations is presented in Appendix D together with available numerical results.

M. Maintenance and Operating Expenses

The annual maintenance and operating costs in the model are the algebraic sum of two components. The first component is the normal average cost per mile ACMA0(IATYP, IHTYP), which is dependent on area type and highway type. The second component is the change or increment in maintenance and operating costs arising from the countermeasure.

The individual countermeasures influence maintenance and operating expenses in one of two ways. Those countermeasures that add equipment (signing, markers, lights) or new pavement (turning lanes, climbing lanes, widened traveled way) or other structures increase maintenance and operating expenses. On the other hand, those countermeasures that renew, replace or protect the existing surface course change the sequence of yearly expenses and have a tendency to reduce those expenses in the near future.

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* User costs applicable to specific area and highway types could be added to the model, and would make it useful for benefit-cost calculations applicable to reconstruction that changes highway type.

It was not possible to locate representative data that quantify the relationships described above. Because of the current lack of well-defined data, the model is configured to facilitate sensitivity tests using appropriate analytical forms.

The countermeasures that add equipment, pavement, or structure will clearly add maintenance and possibly operating costs associated with the quantity of the countermeasure employed. The model employs the average annual maintenance and operating cost per unit of countermeasure, CMA0(KM), provided by the support system data files unless the user supplies an overriding value, SCMA0(KM). Although the yearly costs for the maintenance and operation of these countermeasures may exhibit changes with the years of service, the year-to-year variation is not included in the model. Thus, the model uses CMA0(KM) or SCMA0(KM) each year as the second component of the annual maintenance and operating expenses. Examples of such expenses would be sign replacement and cleaning, added winter maintenance for the new pavement, etc.

Countermeasures that consist of surface courses, surface treatments and surface seals influence the subsequent sequence of yearly maintenance expenses. The maintenance costs for the first year following resurfacing can be reduced below the annual average, and they can then increase linearly with time to a maximum where they remain constant. The second component for these countermeasures in the model is the lesser of

$$\mathrm{CMA0(KM)} + \mathrm{JY} * \mathrm{CCMA0(KM)}$$

or

$$\mathrm{CMA0M(KM)}\ ,$$

where CMA0(KM) will usually be negative and CCMA0(KM) , the rate of change, is positive and is multiplied by the number of years, JY , since emplacement. CMA0M(KM) is used to set a maximum for the second component of maintenance and operating cost. Examples of maintenance and operating expenses for these countermeasures are patching and sealing.

N. Traffic Volumes

The measure of traffic volume used by the model is the Average Daily Traffic (ADT). The model considers three types of sites: intersection sites, non-intersection sites (see Section VI.B) and highway sections. The model has the capability to handle traffic volumes for either one or two facilities at each site. At an intersection site, one of the intersecting roadways is designated as the major facility and the other is designated as the secondary facility. In this case, the user must supply traffic volume estimates for both facilities. For highway sections and non-intersection sites, traffic volumes are needed for only one facility--the major facility.

The model requires an estimate of ADT for each facility in each year of the analysis period. The user can specify these traffic volumes by either of two alternative methods: (1) by specifying the ADT for the year when implementation of the countermeasure is planned and the rate of ADT growth, or (2) by directly identifying the ADT year-by-year for the entire analysis period.

The first method uses the following functional relationship to project the growth of traffic volumes:

$$\text{ADTM}(m) = \text{TIM} + (\text{TIM})\left(\frac{\text{TMGL}}{100}\right)(m) + \text{TIM}\left[\left(\frac{\text{TMGC}}{100} + 1\right)^{m} - 1\right]$$

where ADTM(m) = ADT of major facility in year m,

TIM = ADT of major facility during year when countermeasure is implemented,

TMGL = Percent growth rate for linear ADT growth, and

TMGC = Percent growth rate for compounded ADT growth.

ADT growth for the secondary facility is treated in a similar fashion.

The base for ADT growth, TIM, is the estimated ADT for the year when the countermeasure will be implemented. The user can choose either linear or compound growth for ADT by the selection of values for TMGC and TMGL. For example, if TMGL = 5% and TMGC = 0%, then ADT will have a linear growth at a rate of 5% per year. However, if TMGL = 0% and TMGC = 5%, ADT growth will be at the rate of 5% per year, compounded.

Alternately, the user can specify year-by-year ADT values for both the major and secondary facilities. This option is useful when the ADT growth pattern cannot be specified by a simple percentage rate. For example, an abrupt decrease in traffic volume on a facility, caused by the opening of a parallel facility during the analysis period, cannot be described by a simple function. In such cases, the user can provide the best estimate of ADT for each year of the analysis period.

The model uses the same projected traffic volume data in the analysis of all countermeasures. It assumes that none of the countermeasures has an effect on the traffic volume at the site during the analysis period.

O. Skid Numbers

An in-depth examination was made of the factors that determine skid numbers and of the associated field and laboratory findings. It is clear that skid numbers depend on the aggregate mineralogy, initial shape, size grading, the binder or cement characteristics, the emplacement practices, and various wear and weathering processes after emplacement. These factors are discussed in Appendix B. It is concluded that it is currently impractical to establish numerically defined values for skid numbers that will be appropriate for widespread application to any one of several types of surface courses. Instead, it is clear that even subtle variations in mineralogy, binders and emplacement practices, and the regional variations in wear and weathering combine to make skid number prediction a strictly local necessity.

As a result of the above findings, the computerized model contains a simple analytical form for skid number as a function of accumulated vehicle passages. The form is known to be applicable to pavements with polishing aggregate and it appears to be suitable for nonpolishing aggregate as well.

Within the computerized model the skid number, SN , is calculated as

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SN = SDO + CS * ALOG(AMAX1(1.0, CT/100000.))
```

where SDO = Initial skid number,

CS = A rate of change with the (natural) log of vehicle passages,

CT = Accumulated vehicle passes since surface emplacement,

and the AMAX1 function indicates that 1.0 is used in place of CT/100000. when CT/10000. is less than 1.

In addtion, bounds can be set on the final value of skid number, SDF (when CT is large). If CS is negative (i.e., a polishing aggregate surface), SDF is used as a lower bound for SN. If CS is positive (i.e., a true nonpolishing aggregate surface), SDF is taken as an upper bound for SN .

Within the computerized model the coefficients and limit values are carried as subscripted symbols SDOR(KM), CSR(KM), and SDFR(KM), where the subscript, KM, identifies the countermeasure with those coefficient values.

The skid number calculations for a countermeasure are set up in subroutine SKIDI and are evaluated for each year analyzed in subroutine SKIDC. Routine SKIDC also keeps track of pavement surface life; and, if the period of analysis extends past the end of surface life, the pavement is renewed (analytically) and accumulated traffic passages begin again at zero. For the base case, i.e., the "as is" condition, logic will start CT at a nonzero value for the zeroth year if the pavement has been used and there is no prior decision to alter it.

The skid number is conventionally measured directly with a skid trailer. However, a relationship developed by Penn State University provides estimates of skid number from separate measures associated with surface microtexture and macrotexture. The relationship is:

$$SN_V = (-31.0 + 1.38\ BPN)e^{-[0.041V/(MD)^{0.47}]}$$

where SN_V = Skid number at speed V(mph),

BPN = British Portable Number, and

MD = Mean texture depth (milli-in.) determined by the sand patch method.

The model uses skid number at a speed of 40 mph, so the appropriate form is obtained by substituting 40 mph into the previous equation:

$$SN_{40} = (-31.0 + 1.38\ BPN)e^{-[1.64/(MD)^{0.47}]}$$

This equation is employed in the model for two purposes. First, the initial skid number of a surface course can be specified through BPN and MD. In the computer program the symbol names are BPNR( ) and AMDR( ) where the subscript ( ) identifies the countermeasure. These values are read in subroutine REED. When they are supplied, the skid number calculated from BPNR( ) and AMDR( ) will be used in place of SD0R( ).

The Penn State equation is used in the second application to calculate the skid number for the "as is" pavement. The program user supplies the data with symbol names BPNY0 and AMDY0. These data may be supplied by the user in place of SNY0. However, if SNY0 is supplied as input it will be used.

In either case (new or existing pavement surface) the skid number is subsequent years is calculated using the first equation in this section where skid number is a function of accumulated vehicle passes, CT.

VI. ACCIDENT RATES AND COUNTERMEASURE EFFECTS

The computerized benefit-cost model uses the results from Phase I analyses of the relationships between skid number and accidents. It meshes these with previously published data on the accident reductions achieved through geometric and traffic control countermeasures. This combination gives the model the capability to evaluate the entire range of wet-pavement accident countermeasure types. The analysis of the combined forms also indicates that the effectiveness of geometric and control countermeasures is not independent of skid number.

This section of the report presents the results from Phase I analyses that are directly applied in the model. The relationship of these results to countermeasure effectiveness is shown. The relations employed in the model are derived in brief and the resulting forms are presented. The incorporation of geometric and control countermeasures is described. The influence of ADT on accidents is presented together with the forms employed in the model. Finally, a description is provided of the model's overall handling of accident rate calculations.

A. Results From Analyses of Skid Number and Accident Rates

Three major findings are incorporated in the model. First, there is the general finding that the wet-pavement accident rate, r_w , is correlated with skid number, S , in the anticipated way. That is, the wet-pavement accident rate is decreased for higher skid numbers. The exact relationships are dependent on the area type and highway type, and these relationships are well defined by available data only for rural areas, where sample sizes are largest.

The second major finding is that the relationship between the wet-pavement accident rate, r_w , and skid number, S , is strongly dependent on the dry-pavement accident rate, r_d . This finding is illustrated in Figure 4 where $\frac{\partial r_w}{\partial S}$, the rate of change of the wet-pavement accident rate with skid number, is plotted against the dry-pavement accident rate for all rural highway types. The magnitude of $\frac{\partial r_w}{\partial S}$ is indicative of the relative sensitivity of wet-pavement accident rate to skid number (i.e., the slope of the wet-pavement accident rate-skid number relationship). This sensitivity, which is for the most part in accord with expectations, is now discussed.

In Figure 4, and in the underlying analyses, the dry-pavement accident rate is used as a proxy variable. It is reasoned that where dry-pavement accident rates are relatively low there will be a less-than-average

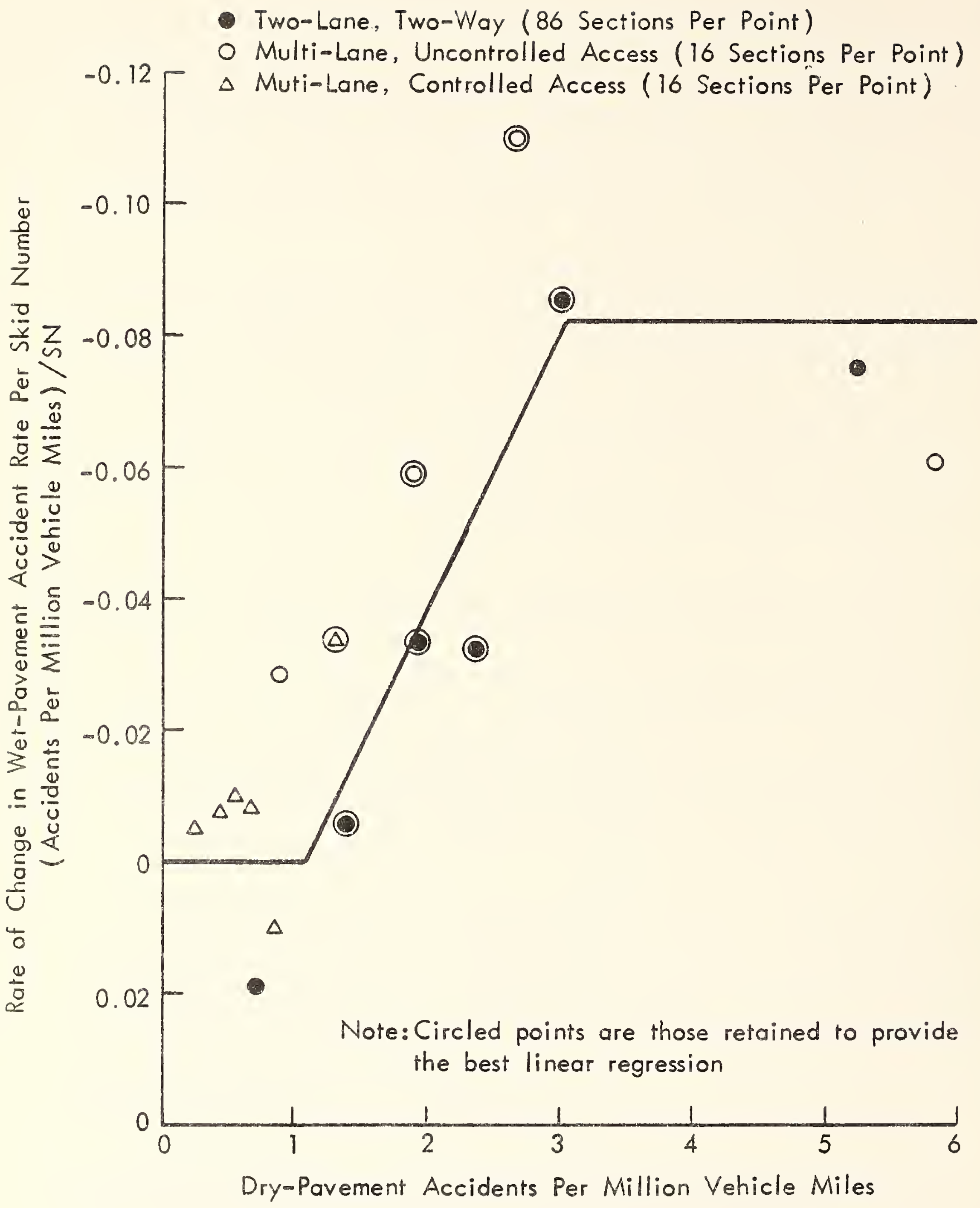

Figure 4 - Rate of Change of Wet-Pavement Accident Rate with Skid Number As a Function of Dry-Pavement Accident Rate for Rural Highways

demand for skid resistance to avoid accidents on wet pavements. This should be associated with a small sensitivity. Likewise, high dry-pavement accident rates are an indication that there will be sizeable demands for skid resistance to avoid accidents on wet pavements. In these cases, the sensitivity should be large in magnitude. The plotted points in Figure 4 generally conform to the preceding concepts. In fact, when the dry-pavement accident rate is used as a factor the sensitivity of wet-pavement accident rate to skid number is explained as well as by any other choice of factors.

The relationship between $\frac{\partial r_w}{\partial S}$ and r_d is approximated in the model by three line segments as shown in Figure 4. At low dry-pavement accident rates, $r_d < 1.08$ accidents/million vehicle miles (MVM), the sensitivity, $\frac{\partial r_w}{\partial S}$, is zero. In the range, $1.08 \leq r_d < 3.02$, the magnitude* of the sensitivity increases linearly, and for $r_d \geq 3.02$ the sensitivity remains constant.** The correlation coefficient of the linear regression line for the range 1.08 r_d 3.02 in Figure 4 is 0.78. This relatively high correlation coefficient should not be misinterpreted. The slopes used in this regression analysis are themselves the result of regression analyses that range in correlation coefficient from 0.02 to 0.33. Therefore, the reliability of Figure 4 to predict the rate of change of wet pavement accident rate with skid number for any particular section is limited. However, Figure 4 is the most reliable representation of the important sensitivity of the slope of the wet-pavement accident rate-skid number relationship to dry-pavement accident rate identified in Phase I. A description of the development of this relationship is found in Volume I.

In the model, it is assumed that the wet-pavement and dry-pavement accident rates prior to application of a countermeasure are known. These initial estimates will be based on historical experience at the site or, in the case of new or rebuilt facilities, on professional judgement considering similar facilities. Then, if a change in skid number is contemplated as a remedial measure, the rate of change of the wet-pavement accident rate with skid number can be estimated.

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* All non-zero values of $\frac{\partial r_w}{\partial S}$ are negative. This is expected, indicating that wet-pavement accident rates diminish as the skid number increases.

** The leveling off of $\frac{\partial r_w}{\partial S}$ at large r_d was not anticipated. There are several potential explanations for this, although none of them have been explored. One possibility involves the kind of rate averaging implicit in using data from sections more than 1 mile long. Another possibility is that on sections with very high dry-pavement accident rates, many of the accidents may arise in situations where moderate changes in skid resistance has little effect.

Although the data on urban sections were not extensive enough to establish separate relationships, statistical tests indicate that the sensitivities for urban areas are likely to be different than the rural values. However, the general character of the relationships should be similar. Lacking definitive data, the rural relationships are applied in the model to urban sites as well as best available estimates.

The third major finding incoporated in the model is the set of regression results that relate dry-pavement and wet-pavement accident rates. Regression equations were obtained separately for each of six combination of area type and highway type. Statistical tests indicated that the intercepts (r_w at $r_d = 0$) are indistinguishable, but that there are two different slopes (dr_w/dr_d) as indicated in Table 1 and Figure 5. Therefore, two distinct relationships between wet- and dry-pavement accident rates are employed in the model. No explicitly determined correlation coefficient was determined for these relationships because of the manner in which the analysis was performed. However, the overall goodness of fit can be judged from the correlation coefficients for the six regression equations used to develop the two relationships. The correlation coefficients for these six range from 0.38 to 0.69. As would be expected, these results indicate that wet-pavement accident rates are generally higher than dry-pavement rates. It is noteable, however, that on rural highways and on urban, two-lane highways, the wet-accident rate does not increase quite as fast as the dry-accident rate.

The relations between wet-pavement and dry-pavement accident rates and the sensitivity of wet-pavement accident rates to skid number were combined in the computerized model. The final forms used are presented in the next section.

B. Basic Equations Depicting Skid Number-Accident Rate Relationships

The incorporation of the skid number-accident rate relationships employs several simple concepts. First, the overall accident rate on a facility is approximated as a linear combination of the rates under wet- and dry-pavement conditions:

$$r = f_w r_w + f_d r_d ,$$

where r = Overall accidents per MVM
f_w = Fraction of time pavement is wet,
r_w = Accidents per MVM under wet-pavement conditions,
f_d = Fraction of time pavement is dry, and
r_d = Accidents per MVM under dry-pavement conditions.

Second, the wet-pavement accident rate is expanded as the sum of a part correlated with the dry-pavement accident rate and a part containing the skid number sensitivity:

$$r_w = b_o + b_1 r_d + \frac{\partial r_w}{\partial S} (S - \overline{S}) ,$$

where b_o and b_1 are coefficients. S is the skid number measured at 40 mph (64 km/hr); and $\overline{S}$ is the average skid number (40 mph or 64 km/hr) for which $r_w = b_o + b_1 r_d$. Table 1 gives the coefficient values, and Table 2 the values for $\overline{S}$.

TABLE 1

REGRESSION COEFFICIENTS, b_o and b_1

Area Highway Type[a]	Common Intercept (b_o)	Common Slope (b_1)
R2LUA	0.8066	0.8281
RMLUA	0.8066	0.8281
RMLCA	0.8066	0.8281
U2LUA	0.8066	0.8281
UMLUA	0.8066	1.4873
UMLCA	0.8066	1.4873

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[a] R2LUA = Rural, two-lane, uncontrolled access.
RMLUA = Rural, multilane, uncontrolled access.
RMLCA = Rural, multilane, controlled access.
U2LUA = Urban, two-lane, uncontrolled access.
UMLUA = Urban, multilane, uncontrolled access.
UMLCA = Urban, multilane, controlled access.

TABLE 2

AVERAGE SKID NUMBERS AT 40 MPH (64 KM/HR)

Area, Highway Type	Average Skid Number at 40 mph (64 km/hr)	Sample Size	Unweighted Averages Employed in Model
R2LUA	47.97	518	
RMLUA	45.50	97	
RMLCA	44.59	97	
All Rural (weighted)	47.17	712	46.0
U2LUA	41.04	32	
UMLUA	38.90	34	
UMLCA	39.27	28	
All Urban (weighted)	39.74	94	39.7

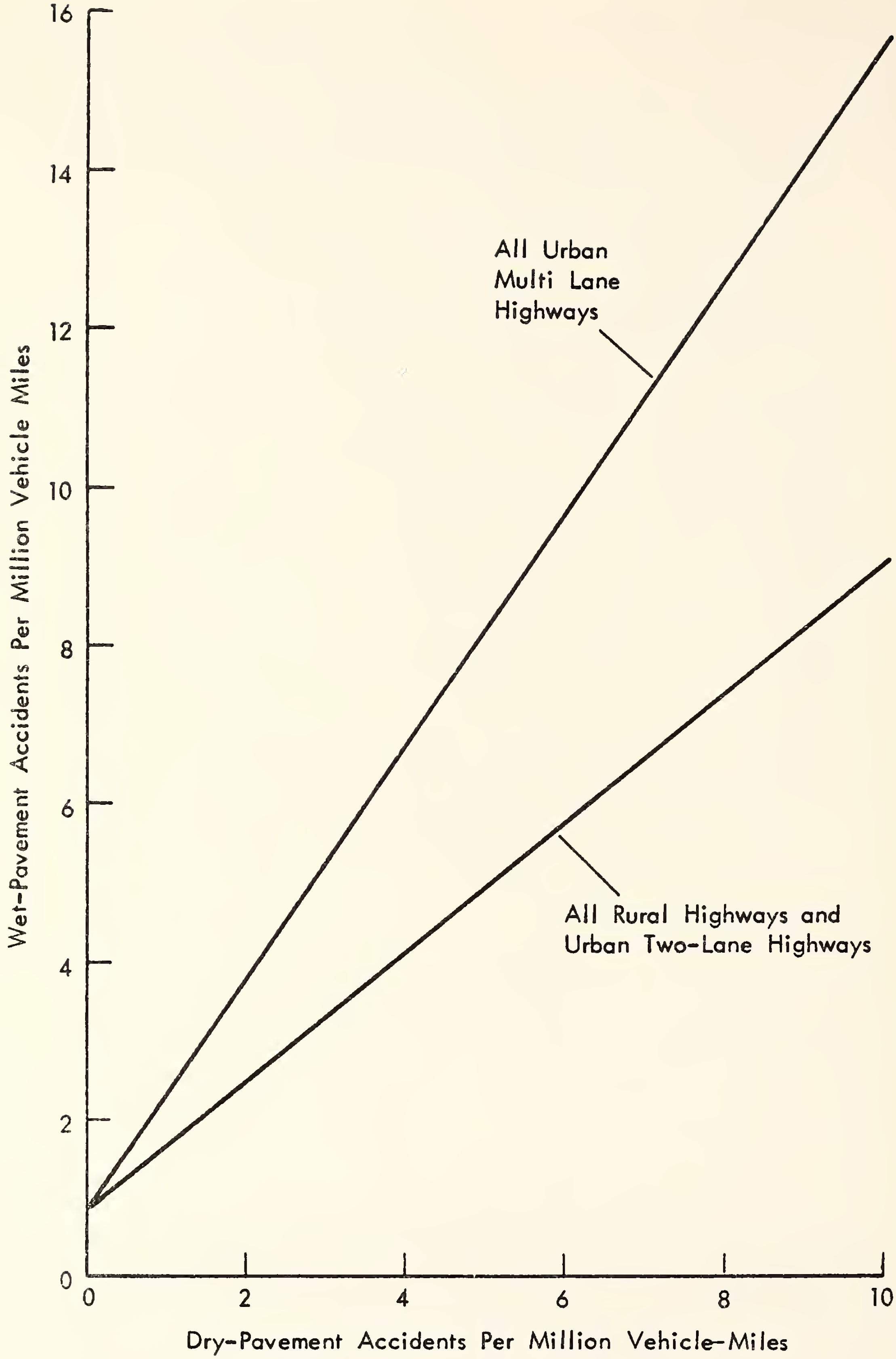

Figure 5 - Relation Between Dry-Pavement and Wet-Pavement Accident Rates

In addition, in agreement with Figure 4, a three segment representation for $\frac{\partial r_w}{\partial S}$ is employed where each segment has the form

$$\frac{\partial r_w}{\partial S} = a_o + a_1 r_d$$

where the coefficients, a_o and a_1, given in Table 3, depend on the dry-pavement accident rate. However, as will be shown subsequently, it is practical to select the appropriate a_o and a_1 on the basis of overall accident rate.

TABLE 3

REGRESSION COEFFICIENTS a_o AND a_1 [a/]

Range of r_d	a_o	a_1
$0 \leq r_d \leq 1.082$	0	0
$1.082 < r_d < 3.02$	0.04615	-0.04264
$3.02 \leq r_d$	-0.0825	0

[a/] The coefficients are based on all rural highway types combined, but are used for urban highways as well, because of a lack of more definitive data (see text, Section VI.a).

C. Graphical Visualization of Countermeasure Effects

Figures 6 and 7 illustrate overall accident rates as functions of skid number and dry-pavement accident rate for climates that produce wet highways 10% and 30% of the time. These figures were plotted from the equations in the preceding section.

The effects of countermeasures can be visualized on either figure. When a geometric or traffic control countermeasure is applied, the improvement is reflected by a displacement along the line of constant skid number to a lower accident rate. When the skid number is increased, the improvement is reflected by a vertical displacement to lower total accident rate (presumably, at a constant dry-pavement accident rate). Some countermeasures may involve both effects. For instance, pavement grooving appears to influence both wet- and dry-pavement accident rates at some sites. The grooves may act to alert drivers under all conditions.

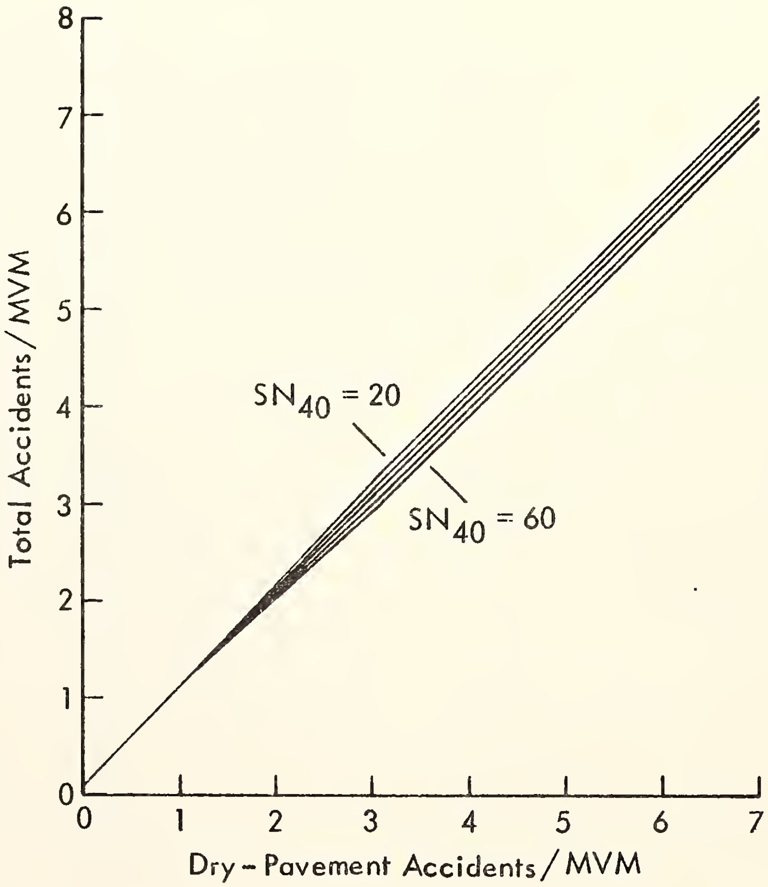

Figure 6 - Overall Rural Accident Rate Versus Dry-Pavement Accident Rate and Skid Number, When Pavement is Wet 10% of Time

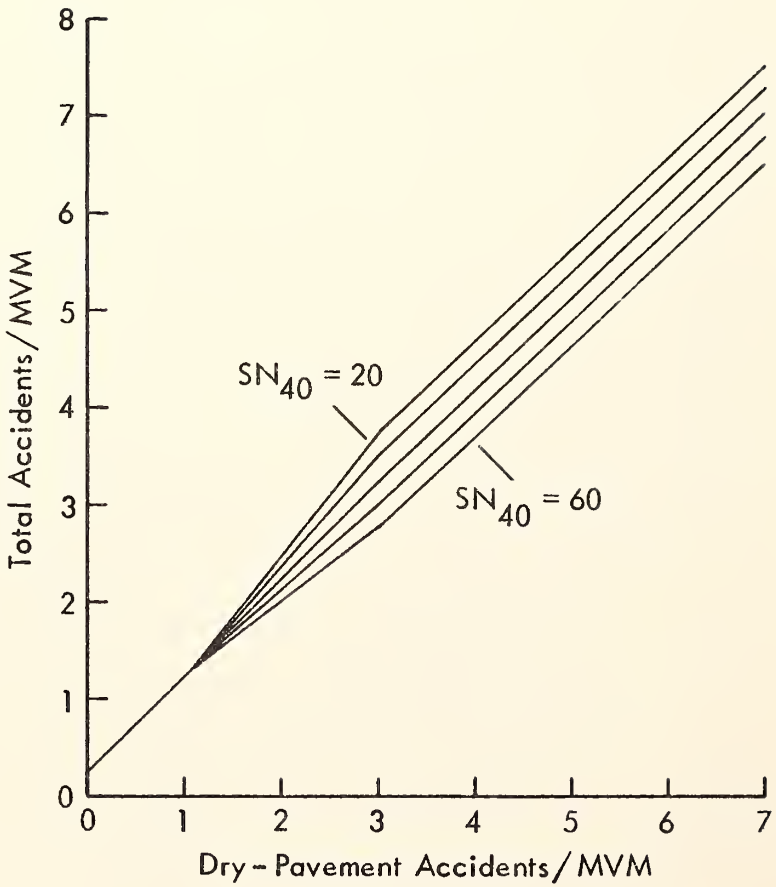

Figure 7 - Overall Rural Accident Rate Versus Dry-Pavement Accident Rate and Skid Number, When Pavement is Wet 30% of Time

Figure 6 illustrates the small effect of skid number on overall accident rates when the pavement is wet only 10% of the time. Similarly, on sections with low dry-pavement accident rates, the data collected in this project indicates there is no sensitivity to skid number. Therefore, (quite logically) skid number improvements are most likely to be cost beneficial on sections with relatively high accident rates and where pavements are wet a large fraction of the time.

The figures suggest that maximum benefits accrue at very high skid numbers (60). These benefits should be viewed with reservation. First, a skid number of 60 is close to the maximum attainable with special surface courses incorporating either rare or manufactured aggregate. Second, although the $\partial r_w / \partial S$ is constant according to the data analyses, the confidence interval is wide at extreme skid numbers.

There is another aspect that deserves attention. At high accident rates the overall accident rate is less than the dry-pavement rate for large skid numbers. This situation arises because the predictor equations yield wet-pavement accident rates less than dry-pavement rates when there are large skid numbers in conjunction with large dry-pavement accident rates. It is difficult to determine if this phenomenon is real. Certainly there are numerous facets of driving other than skid resistance that deteriorate in wet weather. The visual aspects are most obvious--more obscuration, reduced visual range, reduced contrast during daytime, and increased glare at night. Factors that might decrease wet-weather accidents are less obvious. Field measurements indicate that average speeds are reduced very little in wet weather. However, it may be more important to know if the speed distribution is affected, with reductions in the extremely high speeds. For example, previous analyses of speeds in horizontal curves[61a/] suggest that the highest speeds then must be reduced on wet pavements to avoid frequent skidding.

Available information is not sufficient to evaluate the likelihood that wet-pavement accident rates may be less than dry-pavement rates under some conditions. In any event, the benefits indicated for very high skid numbers may be overestimated.

D. Forms Employed In the Model

The equations presented in Section B can be combined to form the basic equation:

$$r = f_w \left[b_o + b_1 r_d + (a_o + a_1 r_d) \; (S - \bar{S}) \right] + f_d r_d \; .$$

The change in overall accident rate with skid number is given by the partial derivative:

$$\frac{\partial r}{\partial S} = (a_o + a_1 r_d) f_w \ .$$

Thus, an incremental change in skid number (ΔS) will produce an incremental change in overall accident rate (Δr) of

$$\Delta r = \frac{\partial r}{\partial S} \Delta S$$

$$= (a_o + a_1 r_d)(\Delta S) f_w \ .$$

Using the basic equation and the forms illustrated in Figure 4, the expression, $\frac{\partial r}{\partial S}$, can be obtained as

$$\frac{\partial r}{\partial S} = 0$$

for $r \le r_1 = f_w \left[b_o + 1.082\ (b_1 - 1)\right] + 1.082.$

If $r > r_1$,

$$\frac{\partial r}{\partial S} = -0.0825\ f_w$$

or

$$f_w\ (r - r_1) a_1 / \left\{ f_w \left[b_1 + a_1\ (S_o - \bar{S})\right] + (1 - f_w) \right\} \ ,$$

whichever is algebraically larger. S_o is the skid number applicable when r was established as the accident rate, and normally is the skid number prior to a change due to countermeasure implementation or pavement use. The coefficients for these equations have values that depend only on area type and highway type. They are summarized in Table 4.

These equations together with the coefficients in Table 4 are employed in the model to calculate $\partial r/\partial S$ and then adjust the accident rate for changes in skid number. The equations are in subroutine SNADJ where $\partial r/\partial S$ has the symbol name, DRDS , the incremental change in skid number is SN-SN0LD , and overall accident rate has the symbol name ARC.

TABLE 4

SUMMARY OF COEFFICIENTS FOR EQUATIONS EMPLOYED IN MODEL

Area Highway Type[a]	$\bar{S}$	a_1	b_o	b_1
R2LUA	46.0	-0.64264	0.8066	0.8281
RMLUA	46.0	-0.64264	0.8066	0.8281
RMLCA	46.0	-0.64264	0.8066	0.8281
U2LUA	39.7	-0.64264	0.8066	0.8281
UMLUA	39.7	-0.64264	0.8066	1.4873
UMLCA	39.7	-0.64264	0.8066	1.4873

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[a] R2LUA = Rural, two-lane, uncontrolled access.
RMLUA = Rural, multilane, uncontrolled access
RMLCA = Rural, multilane, controlled access.
U2LUA = Urban, two-lane, uncontrolled access.
UMLUA = Urban, multilane, uncontrolled access.
UMLCA = Urban, multilane, controlled access.

The Phase I analyses indicate that wet pavements and skid numbers can also impact the effectiveness of geometric and traffic control countermeasures. This is apparent from Figures 6 and 7, where such countermeasures can be thought of as acting directly on the dry-pavement accident rate. When the dry-pavement accident rate is reduced by a fixed percentage, the reduction in total accidents is sensitive to the fraction of time pavements are wet, and to the skid number if the accident rate is in the middle range where the lines fan out. In this range a low skid number should cause the geometric or control countermeasures to be relatively more effective.

The skid numbers and the fractions of time that pavements were wet during countermeasure evaluations will affect the results of those evaluations. The basic equation for overall accident rate can be applied to determine a factor to correct the evaluated percent reduction, P, to the percent, p, that can be expected in application:

$$p = \left\{ \frac{f_w \left[b_1 + a_1 \ (S - \bar{S}) \right] \ + f_d}{(F_w b_1 + F_d)} \right\} P$$

where F_w and F_d = Fractions of time pavements in the countermeasure evaluation region were wet and dry,

and the other symbols retain their previous meanings. The variable, a_1, depends upon the dry-pavement accident rate at the application site, so must be approximated using the initial overall accident rate at the application site. The coefficient of P is the correction factor; it has the symbol name GCØR and is calculated in subroutine CØRRT.

Spot-site accident rates are also treated by the model. However, the data and analyses from Phase I deal with accident rates (accidents/MVM) on sections of highway, whereas at spot sites it is conventional to use accidents/MV. In the model, it is postulated that the spots in question have higher than average accident rates, so that the sensitivity to skid number should be equal to or greater than the sensitivity in highway sections. Although the leveling off of that sensitivity at very high accident rates on sections raises questions about the postulate, the postulate of similarity between spots and sections still provides the only estimate and it is used.

Analytically in the model it is assumed that each spot site analyzed has an initial accident rate that is equivalent to the section rate at the upper end of the middle range. (This is at the upper end of the fan of lines on Figures 6 and 7.) Using this assumption the precounter measure (year zero) accident numbers are used to calculate a pseudo length for the spot; it is given the symbol name SLGTH. This calculation is in subroutine CØRRT. The modifications and adjustments to accident rate are then handled by the same logic employed for sections.

E. Macrotexture - Accident Rate Relations

Macrotexture influences wet-pavement accident rates through its effect on skid number. The Penn State equation, described in V-0, which quantifies the effect is employed in the model. However, macrotexture is also thought to influence through its effect on the potential for hydroplaning. Analyses to date of available data have not been able to quantify this effect. As described in Volume I of this report, it is possible that the analyses of wet-pavement accident rate-macrotexture correlation have been diluted by variances that could be reduced. The reduction of unnecessary variance might be accomplished by using weight factors based on the established correlations with dry pavement accident rate. If additional relationships between macrotexture and wet-pavement accident rates become available they should be incorporated in the model. The following paragraphs describe the routines that may be affected.

In system files, it will be necessary to provide subscripted symbols for the pertinent measure of initial macrotexture for each countermeasure involving the pavement surface. If mean texture depth is a satisfactory measure the subscripted variable AMDR( ) will suffice.

In input routines, provision will be required for a macrotexture measure for the existing pavement surface. If mean depth is used AMDY0 will suffice.

In all the following routines, provisions should be made to use suitable average values if the macrotexture data is not supplied.

In subroutine C0RRT, it may be necessary to adjust the benefits expected from nonsurface countermeasures for the effects of zero-year macrotexture.

In subroutine SKIDI, set parameter values for calculation of macrotextures during the period of analysis.

In subroutine SKIDC, provide for updating macrotexture for each year of the analysis period, or for reinstating macrotexture to new pavement value in any year when the surface is replaced.

In subroutine SNADJ, provide for change in wet-pavement accident rate due to change in macrotexture.

F. Accident Rates Associated With Geometric and Traffic Control Countermeasures

One of the most useful features of the model is its ability to compare the effectiveness of geometric and traffic control countermeasures with the effectiveness of countermeasures that involve modification of pavement surface characteristics. Although the state-of-the-art of accident reduction effectiveness estimates for geometric and traffic control countermeasures is limited, those estimates that are available from previous research have been incorporated in the model. The user has the option of replacing the effectiveness estimates taken from the literature with estimates more appropriate to a particular region or a particular site. In addition, countermeasures other than those explicitly incorporated in the model can be evaluated using user-supplied effectiveness estimates.

Table 5 presents the accident reduction effectiveness estimates from the literature that are incorporated in the model. These estimates are expressed as percent accident reductions which are applied to the accident experience for the site under analysis. The effectiveness estimates found in Table 5 were obtained from the User's Manual in NCHRP Report 162.[43] The estimates in that manual were obtained from a study conducted in 1966 by Roy Jorgensen and Associates[44] and from estimates supplied directly by the States of California and Mississippi. The estimates in Table 5 are the most reliable that are currently available. However, as more reliable estimates become available in the future, the estimates currently incorporated in the model can be replaced.

Table 5 contains the following information for each geometric and traffic control countermeasure incorporated in the model:

- Site type for which countermeasure is appropriate
- Indication of whether or not the countermeasure may require acquisition of additional right-of-way
- Number used to identify the countermeasure in the model
- Countermeasure name
- Area type for which accident reduction effectiveness estimates are appropriate
- Highway type for which accident reduction effectiveness estimates are appropriate
- Fraction of time with wet pavement for which accident reduction effectiveness estimates are appropriate

TABLE 5

GEOMETRIC AND TRAFFIC CONTROL COUNTERMEASURES INCORPORATED IN THE MODEL

Countermeasure Number	Countermeasure	Area Type	Highway Type	Fraction of Time with Wet Pavement	Percent Reduction All Accidents	Percent Reduction by Severity		Percent Reduction by Accident Type									Percent Reduction by Pavement Condition		Percent Reduction by Light Condition	
						Fatal and Injury	Property Damage Only	Head On	Rear End	Side Swipe	Right Angle	Left Turn	Parking Related	Fixed Object	Pedestrian	Other	Wet	Dry	Night	Day
SITE TYPE 1 - ROUTE SECTIONS																				
Countermeasures which do not require additional right-of-way																				
22	Install/improve edge marking	1	1	0.13	14	17	12													
23	Install right edge lines	1	2	0.13	2															
24	Install right edge lines	2		0.13	2															
25	Install double-yellow median line			0.13	5															
26	Install reflectorized raised pavement markers			0.13	5															
27	Upgrade signs			0.20				20	10	0	0	0	0	0	0	0				
28	Install/improve warning signs	1	1	0.13	36	32	38													
29	Install/improve warning signs	1	2	0.13	18	2	27													
30	Install/improve warning signs	2	1	0.13	14															
31	Install/improve warning signs	2	2	0.13	20	26	17													
32	Install overhead warning signs			0.20				0	20	0	20	20	0	0	0	0				
33	Install overhead lane signs			0.20				0	10	20	0	0	0	0	0	0				
34	Eliminate parking	2	2	0.13	32	3	46													
35	Increase sight distance			0.20				20	0	0	20	20	0	0	0	0				
36	Shoulder stabilization	1	1	0.13	38	46	33													
37	Relocate fixed objects																			
38	Grooving																			

TABLE 5 (continued)

Counter-measure Number	Countermeasure	Area Type	Highway Type	Fraction of Time with Wet Pavement	Percent Reduction All Accidents	Percent Reduction by Severity		Percent Reduction by Accident Type									Percent Reduction by Pavement Condition		Percent Reduction by Light Condition	
						Fatal and Injury	Property Damage Only	Head On	Rear End	Side Swipe	Right Angle	Left Turn	Parking Related	Fixed Object	Pedestrian	Other	Wet	Dry	Night	Day
SITE TYPE 1 - ROUTE SECTIONS																				
Countermeasures which may require additional right-of-way																				
95	Add painted/raised median	2	2	0.13	12															
96	Widen shoulder-no dimensions given	1	1	0.13	-2	7	-7													
97	Widen traveled way-no dimensions given	1	1	0.13	38	30	43													
98	Widen traveled way from 9-ft lanes	1	1	0.13	38	16	51													
99	Widen traveled way from 10-ft lanes	1	1	0.13	5															
100	Modernization to design standards	1	1	0.13	10															
101	Modernization to design standards	1	2	0.13	15	22	12													
102	Reconstruct roadway			0.20				20	10	0	0	0	0	0	0	0				
SITE TYPE 2 - HORIZONTAL CURVES																				
Countermeasures which do not require additional right-of-way																				
39	Install delineators	1	1	0.13	2	16	-6													
40	Install delineators	1	2	0.13	46	-10	61													
41	Install reflectorized guide markers			0.13	30															
42	Install/improve warning signs	1	1	0.13	57	71	23													
43	Install/improve warning signs	1	2	0.13	52	40	59													
44	Install warning signs and delineators	1	2	0.13	22	41	12													
45	Install warning signs and delineators	2	2	0.13	20	-27	42													
46	Install curve warning arrows			0.13	20															
47	Install advance curve warning sign with advisory speed			0.13	20															
48	Install special curve warning			0.13	75															
49	Install advance warning flashers																			
50	Grooving																			

TABLE 5 (continued)

Countermeasure Number	Countermeasure	Area Type	Highway Type	Fraction of Time with Wet Pavement	Percent Reduction All Accidents	Percent Reduction by Severity		Percent Reduction by Accident Type									Percent Reduction by Pavement Condition		Percent Reduction by Light Condition	
						Fatal and Injury	Property Damage Only	Head On	Rear End	Side Swipe	Right Angle	Left Turn	Parking Related	Fixed Object	Pedestrian	Other	Wet	Dry	Night	Day
SITE TYPE 2 - HORIZONTAL CURVES																				
Countermeasures which may require additional right-of-way																				
103	Reconstruct curve	1	1	0.13		89	96													
SITE TYPE 2 - GRADES																				
Countermeasures which do not require additional right-of-way																				
51	Install centerline striping at crests	1	1	0.13	64															
Countermeasures which may require additional right-of-way																				
104	Add climbing lane	1	1	0.13	0															
SITE TYPE 2 - MEDIAN OPENING																				
Countermeasures which do not require additional right-of-way																				
52	Close median opening			0.20				100	50	50	100	100	0	0	0	0				
SITE TYPE 2 - BRIDGE																				
Countermeasures which do not require additional right-of-way																				
53	Install delineators	1	1	0.13	47	-8														
54	Install delineators	1	2	0.13	53															
55	Install reflectorized guide markers			0.13	40															
56	Install new safety lighting			0.13															50	0
SITE TYPE 2 - UNDERPASS																				
Countermeasures which do not require additional right-of-way																				
57	Install delineators	1	1	0.13	47	-8														
58	Install delineators	1	2	0.13	53															
59	Install reflectorized guide markers			0.13	40															
60	Install new safety lighting			0.13															10	0

TABLE 5 (continued)

Countermeasure Number	Countermeasure	Area Type	Highway Type	Fraction of Time with Wet Pavement	Percent Reduction All Accidents	Percent Reduction by Severity: Fatal and Injury	Percent Reduction by Severity: Property Damage Only	Percent Reduction by Accident Type: Head On	Rear End	Side Swipe	Right Angle	Left Turn	Parking Related	Fixed Object	Pedestrian	Other	Percent Reduction by Pavement Condition: Wet	Dry	Percent Reduction by Light Condition: Night	Day
SITE TYPE 2 - RAILROAD CROSSING																				
Countermeasures which do not require additional right-of-way																				
61	Install flashing beacons			0.13	80															
62	Install new safety lighting			0.13															60	0
SITE TYPE 3 - INTERSECTIONS																				
Countermeasures which do not require additional right-of-way																				
63	Install 4-way STOP signs	2	1	0.13	68	67	68													
64	Install minor leg STOP control (at locations where angle accidents exceed 50% of all accidents)	1	1	0.13	65	89	51													
65	Install minor leg STOP control (at locations where angle accidents exceed 50% of all accidents)	2	1	0.13	48	71	37													
66	Install minor leg STOP control (at locations where angle accidents exceed 50% of all accidents)	2	2	0.13	38															
67	Install YIELD sign	2	1	0.13	59	80	49													
68	Install YIELD sign	2	2	0.13	-46															
69	Install STOP AHEAD sign	1	1	0.13	47	96	18													
70	Install advance warning flashers			0.13	30															
71	Install flashing red-yellow warning beacons			0.13	50															
72	Install 4-way flashing red beacons			0.13	75															
73	Install new traffic signals (at locations where angle accidents exceed 60% of all accidents)	1	2	0.13	29	50	17													

TABLE 5 (continued)

Countermeasure Number	Countermeasure	Area Type	Highway Type	Fraction of Time with Wet Pavement	Percent Reduction All Accidents	Percent Reduction by Severity		Percent Reduction by Accident Type									Percent Reduction by Pavement Condition		Percent Reduction by Light Condition	
						Fatal and Injury	Property Damage Only	Head On	Rear End	Side Swipe	Right Angle	Left Turn	Parking Related	Fixed Object	Pedestrian	Other	Wet	Dry	Night	Day
SITE TYPE 3 - INTERSECTIONS																				
Countermeasures which do not require additional right-of-way																				
74	Install new traffic signals (at locations where angle accidents exceed 60% of all accidents)	2	2	0.13	29	50	19													
75	Install new traffic signals			0.13	27															
76	Remove existing traffic signal			0.20				0	90	0	0	0	0	0	0	0				
77	Improve signals at 4-leg intersection	1	2	0.13	42	45	40													
78	Improve signals at 4-leg intersection	2	1	0.13	31	35	29													
79	Improve signals at 4-leg intersection	2	2	0.13	-2	10	-8													
80	Improve signals at T intersection	2	2	0.13	57	57	57													
81	Modifty signals			0.13	27															
82	Install 12-in. signai lenses			0.20				0	10	0	0	0	0	0	0	0				
83	Install optically programmed signal			0.20				20	10	10	10	0	0	0	0	0				
84	Install left-turn phase			0.20				0	10	0	0	50	0	0	0	0				
85	Improve signal timing			0.20				0	10	0	10	10	0	0	0	0				
86	Actuate signals			0.20					10	20	10	10	0	0	0	0				
87	Install pedestrian signal phase	2		0.20				0	0	0	0	0	0	0	60	0				
88	Add left turn signal without left turn lane	2	2	0.13	39	57														
89	Improve timing, install 12-in. lens, install turn phase and actuate signal			0.20				0	20	10	20	20	0	0	0	0				
90	Prohibit left turns	2	2	0.13	40	39	40													
91	Improve pavement markings			0.20				0	0	20	10	10	0	0	10					
92	Install rumble strips at non-signalized intersections	1	1	0.13	27															
93	Install safety lighting			0.13															75	0
94	Upgrade safety lighting			0.13															50	0

TABLE 5 (continued)

Countermeasure Number	Countermeasure	Area Type	Highway Type	Fraction of Time with Wet Pavement	Percent Reduction All Accidents	Percent Reduction by Severity		Percent Reduction by Accident Type									Percent Reduction by Pavement Condition		Percent Reduction by Light Condition	
						Fatal and Injury	Property Damage Only	Head On	Rear End	Side Swipe	Right Angle	Left Turn	Parking Related	Fixed Object	Pedestrian	Other	Wet	Dry	Night	Day
SITE TYPE 3 - INTERSECTIONS																				
Countermeasures which may require additional right-of-way																				
105	Add left turn lane without signal	1	2	0.13	-6	-16	-1													
106	Add left turn lane without signal	2	1	0.13	19	80	-9													
107	Add left turn lane without signal	2	2	0.13	6	54	-17													
108	Add left turn lane without signal at T intersection	2	1	0.13	79															
109	Add left turn lane without signal at T intersection	2	2	0.13	51	62	46													
110	Add left-turn lane without signal at Y intersection	1	1	0.13	33															
111	Add left-turn lane with raised/curbed island at non-signalized intersection	1		0.13	60															
112	Add left-turn lane with raised/curbed island at non-signalized intersection	2		0.13	70															
113	Add left-turn lane with painted island at non-signalized intersection	1		0.13	60															
114	Add left-turn lane with painted island at non-signalized intersection	2		0.13	15															
115	Add left-turn lane and signal	1	2	0.13	43	58	35													
116	Add left-turn lane and signal	2	2	0.13	27															
117	Add left-turn lane and signal at T-intersection	1	2	0.13	-42	-28	-49													

TABLE 5 (concluded)

SITE TYPE 3 - INTERSECTIONS (concluded)

Countermeasures which may require additional right-of-way (concluded)

Countermeasure Number	Countermeasure	Area Type	Highway Type	Fraction of Time with Wet Pavement	Percent Reduction All Accidents	Percent Reduction by Severity		Percent Reduction by Accident Type									Percent Reduction by Pavement Condition		Percent Reduction by Light Condition	
						Fatal and Injury	Property Damage Only	Head On	Rear End	Side Swipe	Right Angle	Left Turn	Parking Related	Fixed Object	Pedestrian	Other	Wet	Dry	Night	Day
118	Add left-turn lane at signalized intersection without separate left-turn phase			0.13	15															
119	Add left-turn lane at signalized intersection with separate left-turn phase			0.13	36															
120	Add left-turn lane, signal and illumination	2	2	0.13	46	76	32													

Key

Area Type:
1 = Rural
2 = Urban

Highway Type:
1 = Two-Lane, Uncontrolled Access
2 = Multilane, Uncontrolled Access

Blank area type and highway type designations indicate that the effectiveness estimate for that countermeasure can be applied to any area type or highway type without generating an error message.

Blank percent reductions indicate that the accident breakdown is not used for that countermeasure unless specified by the user.

Negative percent reductions are interpreted as percent increases.

- Percent accident reduction effectiveness for all accidents or for accidents broken down by severity, accident type, pavement condition or light condition*

The accident reduction effectiveness of each countermeasure specified by the user is evaluated in Subroutine GREDU, presented in Appendix E. The purpose of this subroutine is to determine the total of fatal-plus-injury accidents and the number of property-damage-only accidents that remain in the year after the countermeasure is implemented. The following discussion describes the use in this subroutine of each type of information described in Table 5.

1. Selection of countermeasures for analysis: The user may select one or more countermeasures that are appropriate for a given site by specifying the countermeasure numbers given in Table 5. The user must exercise judgment in selecting the countermeasures to be analyzed. The burden is on the user to decide whether each potential countermeasure is warranted and feasible.

Many of the countermeasures in Table 5 are applicable to all highway types and area types, but the estimates for some countermeasures are only applicable to certain specified area types or highway types. For example, the accident reduction effectiveness estimate for installation or improvement of edge markings, the first countermeasure shown in Table 5, is only applicable to rural, two-lane highways. If the user specifies this countermeasure for use with any other highway type or area type, an appropriate message will be printed to warn the user. However, since appropriate effectiveness estimates for other highway types and area types are often not available, this message does not prevent the program from performing the analysis of the countermeasure, because the estimate, however inappropriate, may be the best available.

Similarly, the program will check whether each countermeasure selected by the user is appropriate for the site being analyzed. Three types of sites can be analyzed: (1) route sections, (2) non-intersection locations such as horizontal curves, grades, median openings, bridges, underpasses and railroad crossings, and (3) intersections. Each of the countermeasures in Table 5 are identified as appropriate to one of these three site types. The computer program will compare the actual site type with the site type appropriate for each countermeasure specified by the user. If any discrepancies are found a message will be printed to warn the user that the accident reduction effectiveness for the countermeasure he has specified may not be appropriate for the type of site under analysis. As with area type and highway type, the program will still complete the analysis of the countermeasure, even if an inappropriate site type is detected.

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* There are no entries in the pavement condition columns and very few entries in the light condition columns in Table 5. However, these two breakdowns are included in the program logic so that the user can supply countermeasures not incorporated in the model that use these categories.

The countermeasures are also classified by whether or not they may require the acquisition of additional right-of-way. This classification is necessary because countermeasures that may require additional right-of-way employ different subscript ranges than countermeasures that do not require additional right-of-way, as explained in Section V.I.

2. Countermeasure effectiveness estimates: The program will automatically use the effectiveness estimate contained in Table 5 for a countermeasure unless the user provides another estimate for one or more of the selected countermeasures. It is mandatory only that the user supply an effectiveness estimate for those countermeasures that are not included in Table 5 or that have no effectiveness estimate shown there. An error message will be printed if the user does not provide an effectiveness estimate for a countermeasure which requires one. The countermeasure in question will not be analyzed, but analysis of the remaining countermeasures will continue.

As stated above, the accident reduction effectiveness estimates used by the model are expressed by one of five methods:

- Percent reduction by accident severity
- Percent reduction by accident type
- Percent reduction by pavement condition
- Percent reduction by light condition
- Percent reduction for all accidents

Several methods have been used because the effectiveness estimates are presented in the literature in a variety of forms. The five methods are listed above in priority order. The program will use the percent reduction by accident severity for a countermeasure if it is available in Table 5 for the countermeasure in question. If the percent reduction by accident severity is not available, the program will use the percent reduction by accident type, and so on. The percent reduction for all accidents will be used only if the percent reduction is not available for any of the four accident breakdowns.

The countermeasure evaluations in the literature may have been performed under wet-pavement exposure and skid number conditions different from the analysis site. A correction factor is used in the model to make the effectiveness estimates applicable to the wet-pavement exposure and local skid number of the analysis site. The percent reduction from Table 5 is multiplied by the correction factor to obtain an adjusted percent reduction. The correction factor, G, is given by:

$$G = \frac{f_w \left(b_1 + a_1 \left(SN40_o - \overline{SN40}\right)\right) + f_d}{b_1 F_w + F_d}$$

where f_w = Fraction of wet pavement time at site analyzed

f_d = Fraction of dry-pavement time at site analyzed = $1 - f_w$

$SN40_o$ = Skid number (at 40 mph) at site in zeroth year

$\overline{SN40}$ = Average skid number (at 40 mph) for area type and highway type

F_w = Fraction of wet-pavement time at sites where countermeasures were evaluated (given in Table 5)

$F_d = 1 = F_w$

b_1 = Coefficient dependent on highway type and area type (given in Table 6)

a_1 = Coefficient dependent on highway type, area type and overall accident rate (given in Table 6)

The model distinguishes only area type for estimating the average skid number at 40 mph, $\overline{SN40}$. The values assumed in the model for $\overline{SN40}$ are taken from Volume I of this report and are assumed to be 46.0 for rural highways and 39.7 for urban highways. These same values for $\overline{SN40}$ are used regardless of the highway type and site type being analyzed. Note that the sensitivity of the correction factor to skid number is influenced by the coefficient a_1 , which, in turn, is a function of highway type, area type and accident rate. Table 6 indicates that the correction factor is sensitive to skid number only within a limited range of accident rates.

The typical fraction of wet-pavement exposure for the State of Mississippi was determined to be 0.20 from available weather records. Therefore, 0.20 was the value of F_w used for countermeasures from the literature that were evaluated in Mississippi. The other countermeasures in the model were evaluated in the State of California, which has an extremely varied climate, or from data supplied by a number of states. For these countermeasures, a nationwide average value, 0.13, is used for F_w . Table 5 shows the value of F_w used for each countermeasure.

Table 7 illustrates the range of correction factors that can be expected for f_w in the range 0.05 to 0.30 and $SN40_o$ in the range 20 to 60.

3. <u>Calculation of accidents remaining after countermeasure implementation</u>: The user must provide the value of AALL , the total number of accidents expected to occur in the zeroth year if no countermeasure is implemented. If the only available effectiveness estimate for the countermeasure being evaluated is the percent of all accidents reduced, then the expected number of accidents remaining after implementation of the countermeasure is determined directly as:

TABLE 6

VALUES OF a_1 AND b_1 USED TO DETERMINE CORRECTION FACTOR, G

Area Type and Highway Type	Overall Accident Rate Range (accidents/MVM)	a_1
R2LUA RMLUA RMLCA U2LUA	0 to 1.75	0
	1.76 to $(3.50 + 2.5\ f_w)$	-0.04264
	$> (3.50 + 2.5\ f_w)$	0
UMLUA UMLCA	0 to 2.00	0
	2.01 to $(3.50 + 5.0\ f_w)$	-0.04264
	$> (3.50 + 5.0\ f_w)$	0

Area Type and Highway Type	b_1
R2LUA RMLUA RMLCA U2LUA	0.8281
UMLUA UMLCA	1.4873

Key:

f_w = Fraction of time with wet pavement at site analyzed

R2LUA = Rural, Two-Lane, Uncontrolled Access

RMLUA = Rural, Multilane, Uncontrolled Access

RMLCA = Rural, Multilane, Controlled Access

U2LUA = Urban, Two-Lane, Uncontrolled Access

UMLUA = Urban, Multilane, Uncontrolled Access

UMLCA = Urban, Multilane, Controlled Access

TABLE 7

ILLUSTRATIVE VALUES OF THE CORRECTION FACTOR, G

Area Type and Highway Type	f_w	Overall Accident Rate Range (accidents/MVM)	b_1	a_1	Correction Factor, G for $SN40_o$ 20	40	60
R2LUA		0 to 1.75	0.8281	0	1.014	1.014	1.014
RMLUA	0.05	1.75 to 3.63	0.8281	-0.04264	1.071	1.027	0.983
RMLCA		> 3.63	0.8281	0	1.014	1.014	1.014
R2LUA		0 to 1.75	0.8281	0	1.005	1.005	1.005
RMLUA	0.10	1.75 to 3.75	0.8281	-0.04264	1.118	1.031	0.944
RMLCA		> 3.75	0.8281	0	1.005	1.005	1.005
R2LUA		0 to 1.75	0.8281	0	0.988	0.988	0.988
RMLUA	0.20	1.75 to 4.00	0.8281	-0.04264	1.215	1.040	0.866
RMLCA		> 4.00	0.8281	0	0.988	0.988	0.988
R2LUA		0 to 1.75	0.8281	0	0.970	0.970	0.970
RMLUA	0.30	1.75 to 4.25	0.8281	-0.04264	1.310	1.049	0.787
RMLCA		> 4.25	0.8281	0	0.970	0.970	0.970
U2LUA		0 to 1.75	0.8281	0	1.014	1.014	1.014
U2LUA	0.05	1.75 to 3.63	0.8281	-0.04264	1.057	1.013	0.970
U2LUA		> 3.63	0.8281	0	1.014	1.014	1.014
U2LUA		0 to 1.75	0.8281	0	1.005	1.005	1.005
U2LUA	0.10	1.75 to 3.75	0.8281	-0.04264	1.091	1.004	0.916
U2LUA		> 3.75	0.8281	0	1.005	1.005	1.005
U2LUA		0 to 1.75	0.8281	0	0.988	0.988	0.988
U2LUA	0.20	1.75 to 4.00	0.8281	-0.04264	1.160	0.985	0.811
U2LUA		> 4.00	0.8281	0	0.988	0.988	0.988
U2LUA		0 to 1.75	0.8281	0	0.970	0.970	0.970
U2LUA	0.30	1.75 to 4.25	0.8281	-0.04264	1.228	0.966	0.704
U2LUA		> 4.25	0.8281	0	0.970	0.970	0.970
UMLUA		0 to 2.0	1.4873	0	0.963	0.963	0.963
UMLCA	0.05	2.0 to 3.75	1.4873	-0.04264	1.002	0.962	0.922
		> 3.75	1.4873	0	0.963	0.963	0.963
UMLUA		0 to 2.0	1.4873	0	0.986	0.986	0.986
UMLCA	0.10	2.0 to 4.0	1.4873	-0.04264	1.065	0.985	0.905
		> 4.0	1.4873	0	0.986	0.986	0.986

TABLE 7 (Concluded)

Area Type and Highway Type	f_w	Overall Accident Rate Range (accidents/MVM)	b_1	a_1	Correction Factor, G for $SN40_o$ 20	40	60
UMLUA UMLCA	0.20	0 to 2.0	1.4873	0	1.032	1.032	1.032
		2.0 to 4.5	1.4873	-0.04264	1.190	1.030	0.869
		> 4.5	1.4873	0	1.032	1.032	1.032
UMLUA UMLCA	0.30	0 to 2.0	1.4873	0	1.078	1.078	1.078
		2.0 to 5.0	1.4873	-0.04264	1.315	1.074	0.834
		> 5.0	1.4873	0	1.078	1.078	1.078

$$\text{ALTOT} = \frac{(\text{AALL})(100-\text{PRALL}(\text{KM}))}{100}$$

where

ALTOT = Expected number of accidents after implementation of countermeasure KM

AALL = Expected number of accidents if no countermeasure is implemented

PRALL(KM) = Percent accident reduction for all accidents for countermeasure KM

ALTOT is then separated into two components: ALFI and ALPD0 , where ALFI is the number of fatal and injury accidents remaining after implementation of the countermeasure and ALPD0 is the number of property-damage-only accidents remaining after the countermeasure is implemented.

If for any countermeasure, Table 5 contains percent accident reduction by one of the four accident breakdowns, these values will be used rather than the percent reduction for all accidents. The accident totals to which these percent reductions are applied for each category of the accident breakdown used are obtained by the model in one of two ways; either (1) the total number of accidents, AALL , is separated into components by use of typical accident distributions available in the model, or (2) the user supplies the actual number of accidents in each category. The first course is followed if no accident data other than the total number of accidents are available. If the user does have detailed accident data for the site under analysis, he can supply the actual number of accidents in each category of the accident breakdown being used; e.g., if the percent reduction by accident severity is available in Table 5, the user can override the typical distribution of accident severities contained in the model and supply the actual number of fatal, injury, and property-damage-only accidents. This option gives the model great flexibility, since the user can perform a benefit-cost analysis using estimates when very little accident data are available or he can use detailed accident data for the site.

Table 8 presents the distribution of accident severities used by the model for different area and highway types. The model assumes this same distribution of accident severities for all site types. These values were obtained from accident statistics for the entire state highway systems in the States of California, Michigan and Washington. The percentages in Table 8 are used by the model (if the user does not supply accident data by severity) to separate the total number of accidents, AALL , into two components--fatal plus injury, and property-damage-only.

TABLE 8

DISTRIBUTION OF ACCIDENT SEVERITIES BY HIGHWAY TYPE AND AREA TYPE

SOURCE: Compiled from accident statistics for the entire state highway systems of California, Michigan and Washington. The California and Washington data are for the period 1972-5 and the Michigan data are for 1971-4.

	Percent of All Accidents			
	Fatal-and-Injury		Property-Damage-Only	
Highway Type	Rural	Urban	Rural	Urban
Two-Lane, Uncontrolled Access	36.91	31.54	63.09	68.46
Multilane, Uncontrolled Access	35.54	32.17	64.46	67.83
Multilane, Controlled Access	35.49	31.41	64.51	68.60

Table 9 presents the distribution of accident types used by the model for different site and area types. The model assumes this same distribution of accident types for all highway types. This distribution is used to separate AALL into nine components, representing nine different accident types used in the model.

The model assumes that 29.7% of all accidents occur at night and that the remaining 70.3% occur during daylight. These values were adapted from an hourly distribution of accidents in the 1975 edition of Accident Facts,[1] assuming night to be represented by the hours of 7 p.m. to 6 a.m. Similarly, the model assumes that 16.26% of all accidents occur under wet-pavement conditions and the remaining 83.74% of accidents occur under dry-pavement conditions. The values were obtained from data obtained from many states and presented in NCHRP Report 37.[46]

The final step performed by the model in determining the effectiveness of geometric and traffic control countermeasures is to determine the number of accidents remaining in each category of the accident breakdown used as:

$$AL = \frac{(A)(100 - PR(KM))}{100}$$

where AL = Expected number of accidents in a given category after implementation of countermeasure KM

A = Expected number of accidents in the category if no countermeasure is implemented

PR(KM) = Percent accident reduction for accidents in a given category for countermeasure KM

The accidents remaining after countermeasure implementation, AL , are totaled for all categories to obtain the total number of remaining accidents. Finally, if an accident breakdown from Table 5 other than by severity was used, the remaining accidents are separated into fatal-plus-injury and property-damage-only components, designated ALFI and ALPD0 , respectively. If an accident breakdown by severity from Table 5 was used, this final step is unnecessary because ALFI and ALPD0 are available directly.

TABLE 9

DISTRIBUTION OF ACCIDENT TYPES BY AREA TYPE AND SITE TYPE

SOURCE: Adapted from References 1 and 10a.

	Percent of Accidents					
	Rural			Urban		
Accident Type	Highway Section	Non-Intersection Site	Intersection Site	Highway Section	Non-Intersection Site	Intersection Site
Head-on	3.43	4.40	0.67	5.28	6.11	4.09
Rear-end	18.43	19.07	16.62	30.39	36.41	21.94
Sideswipe	13.48	13.89	12.23	6.34	7.32	4.99
Rignt-angle	11.86	0.76	43.46	18.67	0.64	43.99
Left-turn	4.42	3.13	8.07	6.64	2.63	12.26
Parking-related	4.50	6.08	0	15.20	26.03	0
Fixed-object	21.10	25.54	8.46	8.30	11.60	3.61
Pedestrian	1.10	1.21	0.77	2.30	2.40	2.16
Other	21.68	25.92	0.72	6.88	6.86	6.96

G. Influence of ADT on Accident Rate

The analyses of Phase I found that ADT had an influence on accident rates for some area type-highway type combinations. However, the information obtained was not sufficient to quantify the effects of the moderate changes in ADT likely to occur from year to year on an analyzed facility. Consequently, the model employs the regression results developed by Fee.[24a/]

Within the model, an adjustment factor for ADT is evaluated for each year and is applied to adjust the accident rate from the previous year to the year being calculated. The adjustment factor is calculated in subroutine DTADJ. It has the symbol name DTJST and is calculated as the ratio:

DTJST = AJDT/AJTLD

where AJTLD = accident rate based on ADT in previous year,

AJDT = accident rate in current year,

calculated from the referenced regression results as a cubic in ADT:

AJDT = AT3*ADT**3 + AT2*ADT**2 + AT1*ADT + AT0 .

The coefficients depend on area type and highway type and are double subscripted for those designations. The ADT employed is restricted in range so that if the site value falls outside that range it is replaced in the equation with the appropriate limit value. The coefficients and the limit ADT are shown in Table 10.

H. Sequence of Processing Accidents and Accident Costs

The model requires that the analyses at any site begin with the average number of accidents at the site for the year prior to installation of a countermeasure (the "zeroth" year). The zeroth year estimate can be based on historical data or on the program user's professional judgement. The estimate can consist of total accidents or, separately, the property-damage-only accidents and the injury-plus-fatal accidents.

The subsequent processing dealing with accident numbers or rates always employs fractional or incremental changes. This logic preserves the influence of rates or proportions at the analyzed site that may be markedly different from the average for sites with similar area and highway types.

TABLE 10

COEFFICIENTS AND LIMIT ADT FOR AJDT[a/]

Area and Highway Type[b/]	Subscripts	Coefficients				Min ADT /1000	Max ADT /1000	Comments
		AT3	AT2	AT1	AT0			
R2LUA	(1,1)	-0.000,201	0.0362	-0.411	3.489	2.5	12.0	Based on rural, two-lane highway results.
RMLUA	(1,2)	0	0	0	1.0	0	100.0	Table values make accident rate independent of ADT. Fee's[24a/] results for undivided rural highways exhibit a decreasing accident rate with ADT, but no sensitivity for rural, divided highways. These results conflict with the current project findings that show accident rate increasing with ADT.
RMLCA	(1,3)	-0.000,119	0.00690	-0.106	1.364	10.0	31.0	Based on four-lane, rural Interstate results.
U2LUA	(2,1)	-0.000246	0.0324	-0.773	11.50	2.5	23.0	Based on two-lane, urban results.
UMLUA	(2,2)	0	0	0	1.0	0	100.0	Table values make accident rate independent of ADT. Fee's[24a/] results for undivided urban highways exhibit a decreasing accident rate with ADT, but no sensitivity for urban, divided highways. These results conflict with the current project findings that show accident rate increasing with ADT.
UMLCA	(2,3)	-0.000,0181	0.00256	-0.0815	2.174	10.0	60.0	Based on four-lane, urban Interstate results.

[a/] Based on results given by Fee.[24a/]

[b/] R2LUA = Rural, two-lane, uncontrolled access.
RMLUA = Rural, multilane, uncontrolled access.
RMLCA = Rural, multilane, controlled access.
U2LUA = Urban, two-lane, uncontrolled access.
UMLUA = Urban, multilane, uncontrolled access.
UMLCA = Urban, multilane, controlled access.

The first step in accident cost calculations is taken in subroutine ACC0ST where two average costs are calculated. One is for property-damage-only accidents; the other is for combined injury-plus-fatal accidents. The calculations employ the costs of a fatality, an injury, and the per vehicle property damage. The calculations also employ the average numbers of fatalities, injuries and vehicles involved per accident type, which are a function of area type and highway type. The proportions of fatal and of injury accidents also depends on area type and highway type. All these factors are obtained from system files. The cost calculations also employ the separate cost weight factors for fatalities, injuries and property damage supplied by the user. The above calculations and results are independent of countermeasures and the subsequent course of events at the site. All calculations that follow depend on individual countermeasures or on the future of the base condition.

The following sequence of calculations deals with the accident consequences and costs associated with a countermeasure or with the base conditions at the site analyzed. All computer program logic is contained in the large subroutine C0STS, which deals with one countermeasure (or the base condition) at a time. The following description deals with the accident-related logic.

The first major step in C0STS is to calculate the zeroth year accidents with the countermeasure incorporated. (If the base case includes a prior decision to modify the surface and consequently skid number, this change will be included.) The revision of zeroth year accidents due to geometric and traffic control countermeasures is calculated in subroutine GREDU. (Preparation for this calculation is made in preceding subroutines.) After leaving GREDU, where the distribution of severities may change, a cost per accident averaged over all accident severities is calculated for subsequent use. Also, the remaining accident number is converted to a rate.

At this point, a calculation is made for additional zeroth year accidents associated with countermeasure construction, if any. If the countermeasure construction requires lane closure the costs of accidents <u>due to that construction</u> are entered as part of accident costs associated with the countermeasure, even though they occur in the zeroth year.

The next major step, still for the zeroth year, is to adjust the accident rate for the change in skid number. Skid number will change in the zeroth year for countermeasures that change the surface, or, for the base case if there has been a prior decision to modify the surface. After adjustment for skid number the accident rate is the rate that would have occurred in the zeroth year if the countermeasure being processed had been installed and operating for the entire year. Also available is the average cost per accident with the countermeasure installed.

Subsequent processing of accidents and accident costs deals with 1 year at a time for future years 1, 2, etc., through the final year of the period of analyses. For each year the accident rate in the preceding year is the starting point. The rate is adjusted for the effects of change in ADT. Then it is incremented for the change in skid number. Finally, the accident rate, the ADT, the site length, accident increases due to countermeasure construction during the year, and the average cost per accident are combined to obtain the accident costs for the year. These costs are subsequently discounted using economic equations and assembled to provide the equivalent uniform annual accident costs with the countermeasure analyzed.

VII. SUBSCRIPT RANGES FOR COUNTERMEASURES

Subscripts are used to identify countermeasures in the data files and within the computer program. These subscripts are used in the input data to specify the particular countermeasures to be included in the analysis. Certain subscript ranges are reserved in the model for specific types of countermeasures. The boundaries of the reserved subscript ranges are defined by the variables KSM, KM2, KM3, K2 and KMAX in the following manner:

- The subscript 1 is reserved for the initial, base condition, i.e., the "as is" or "as planned" condition.

- Subscripts 2 through KSM are reserved for the countermeasures that involve modification of the pavement surface, such as surface courses, surface treatments and chip and seal coats.

- Subscripts (KSM + 1) through (KM2 - 1) are reserved for the geometric and traffic control countermeasures incorporated in the model (see Section VI.B) that do not require additional right-of-way.

- Subscripts KM2 through (KM3 - 1) are reserved for countermeasures that may require additional right-of-way, including both those incorporated in the model and those supplied by the user.

- Subscripts KM3 through (KM2 + K2 - 1) are reserved for geometric and traffic control countermeasures, supplied by the user, that do not require additional right-of-way.

- Subscripts (KM2 + K2) through (KM3 + K2 - 1) are reserved for right-of-way costs, lives, etc.

- Subscripts (KM3 + K2) through (KMAX - 1) are reserved for additional geometric and traffic control countermeasures, supplied by the user, that do not require additional right-of-way.

- Subscript KMAX is the largest subscript and is reserved for use with Subroutine SIG0, which is intended to calculate whether significant accident reduction savings are possible at the analysis site. This subroutine is not included in the current version of the model, but could be added. Therefore, Subscript KMAX is not currently used by the program logic.

The specific values presently incorporated in the model for the variables that define the boundaries of the subscript ranges are:

KSM = 21
KM2 = 95
KM3 = 127
K2 = 42
KMAX = 180

These values result in the following boundaries for the subscript ranges:

Subscript Range	Type of Countermeasure
1	Initial, baseline condition.
2 - 21	Countermeasures involving pavement surface modification.
22 - 94	Geometric and traffic control countermeasures incorporated in the model that do not require additional right-of-way.
95 - 126	Geometric and traffic control countermeasures that may require additional right-of-way (Subscripts 95 through 120 are reserved for countermeasures incorporated in the model and Subscripts 121 through 126 are reserved for countermeasures supplied by the user).
127 - 136	Geometric and traffic control countermeasures supplied by the user that do not require additional right-of-way.
137 - 168	Right-of-way costs, lives, etc.
169 - 179	Additional geometric and traffic control countermeasures, supplied by the user, that do not require additional right-of-way.
180	Maximum subscript.

If more countermeasures are incorporated in the model in a future revision, the values of KSM, KM2, KM3, K2 and KMAX must be adjusted accordingly.

VIII. INPUT REQUIREMENTS

This section presents the input requirements for the benefit-cost model. The input data items are presented and discussed to the extent necessary for a user to determine their values. For a complete discussion of the manner in which each variable is used in the model, the reader is referred to other sections of this report.

Table 11 identifies the input data that are to be supplied by the user each time the benefit-cost program is run. Additional input to the program is obtained from the cost files that are maintained by the user. The table indicates whether each of the input data items are mandatory or optional. Many of the optional items are included to give the user an opportunity to change the value of a variable from the files for a specific analysis without disturbing the long-term system value. The comment column of the table provides detailed information needed by the user to select values for the input variables.

Table 11 is divided into three sections which deal with general input data, site characteristics, and countermeasures. The following discussion of input requirements is organized in the same manner.

A. General Input Data

The general input data items perform two functions: (1) provide information to be printed in output headings and (2) control the type of analysis performed.

The sequence number, date of analysis and end date of the zeroth year are included because they appear in output headings. The decimal interest rate appears in the output heading, and is also used in the analysis to determine discount factors.

Variables FPD( ), FIA( ), FFA( ), and FUTC( ) are weight factors that can be used to modify the costs of accidents and user time delays incorporated in the model. JPER( ) is used to select the longer or shorter applied life for use as the analysis period, when countermeasures with different applied lives are compared. MXYR sets a limit on the length of the analysis period for all countermeasures considered. Finally, CFAS and CCAS are variables that are not presently used, but could be incorporated in a future version of the model.

TABLE 11

INPUT FOR BENEFIT-COST PROGRAM

Description of Item	Symbol (If Diagrammed)	Optional or Mandatory	Estimated Dimensions	Comment
General Input Data				
Sequence Number for Analysis		Mandatory		Assigned by user.
Date of Analysis		Mandatory		Assigned by user (e.g., 01 31 1977)
Date Zeroth Year Ends		Mandatory		The last day of the year in which the countermeasures will be implemented (e.g., 12 31 1977 = December 31, 1977).
Decimal Interest Rate	V	Optional		User-specified interest rate will replace standard rate obtained from file. Rate is expressed in decimal form (e.g., 0.06).
Subscript for Five Items Which Follow	NVAR	Optional		If NVAR = 1 values are read in; they will write over default values of 1.0 for all cost factors and two for JPER (1). MVAR is largest NVAR used; it could be read in or established by testing NVAR input. If JPER ( ) = 1, logic selects period of analysis as shortest of applied lives of two compared alternatives. If JPER ( ) = 2, period of analysis is longest of the applied lives of two compared alternatives.
Weight Factor for Prop. Damage Only Accident Costs	FPD ( )	Optional	(6)	
Weight Factor for Injury Accident Costs	FIA ( )	Optional	(6)	
Weight Factor for Fatal Accident Costs	FFA ( )	Optional	(6)	
Weight Factor for User Time Delay Costs	FUTC ( )	Optional	(6)	
Code for Period of Analysis	JPER ( )	Optional	(6)	
Upper Limit on Number of Years to be Used in Any Period of Analysis	MXYR	Optional		If read in, will write over default value of 20.
Coefficient for Fraction of Accident Costs Saved in Test for Significant Savings	CFAS	Optional		CFS and CCAS are intended for use in Subroutine SIG0, which may be added to the model at a later date. They have default values of zero. When both CFAS and CCAS are zero, subroutine SIG0 is by-passed.
Coefficient for Amount of Accident Costs Saved in Test for Significant Savings	CCAS	Optional		
Site Characteristics				
Site Description		Mandatory		Assigned by user; maximum of 40 characters on each of two lines.
Numerical Code for State	KSTAT	Mandatory		Assigned by user.
Numerical Code for Region in State	KSTAR	Mandatory		Assigned by user.
Area Type	IATYP	Mandatory		1 = Rural; 2 = Urban

TABLE II (Continued)

Description of Item	Symbol (If Diagrammed)	Optional or Mandatory	Estimated Dimensions	Comment
Highway Type	IHTYP	Mandatory		1 = Two-lane, Uncontrolled Access 2 = Multilane, Uncontrolled Access 3 = Multilane, Controlled Access
Site Type	ISITE	Mandatory		1 = Highway Section 2 = Nonintersection Location 3 = Intersection
Site Length	TLGH	Mandatory		Enter length of facility affected by countermeasure (i.e., length of facility for which accident data are gathered). For intersections use length of major facility.
Fraction of Time Pavement is Wet	FWET	Mandatory		
Average Annual Precipitation (Inches)	APREC	Optional		Value specified by user appears on printed output; not currently incorporated in other program logic
Normal Remaining Life of Facility (Years)	LIFF	Mandatory		
Scheduled or Estimated Years Until Resurfacing	LIFRS	Mandatory		If site is being resurfaced in zeroth year as result of prior decision to resurface or rebuilt, this entry should be the estimated life of the new surface.
Scheduled or Estimated Years Until Rebuilding	LIFRB	Mandatory		If site is being rebuilt in zeroth year as a result of prior decisions, this entry should be estimated interval between rebuildings.
Prior Decision to Resurface	IRS	Mandatory		0 = Prior decision to resurface immediately 1 = No prior decision to resurface immediately
Job Number for Prior Decision		Optional		Assigned by user
Number of Units of Surface Course Which is Planned as Result of Prior Decisions	UN (1)	See comment		Input is mandatory if resurfacing or rebuilding in zeroth year is a result of prior decisions.
Final Capital Worth per Unit of Surface Course Which is Planned as a Result of Prior Decision	FCW (1)	See comment		Same as above.
Current Skid Number	SNY0	Optional		If skid number is available. If user does not enter SNY0, and AMDY0 and BPNY0 were not supplied, the program will use SBAR (IATYP) as default value.
Current or Planned Type of Surface Course	KSW	Optional		User may specify the countermeasure number (KM ≤ KMS) for the type of surface presently in place or planned as a result of a prior decision. Default value = 1.
Current Mean Texture Depth (milli-in.) of Surface Course	AMDY0	Optional		If supplied will be used with BPNY0 to calculate current skid number.
Current British Portable Tester Number	BPNY0	Optional		But must be supplied if AMDY0 is.

TABLE 11 (Continued)

Description of Item	Symbol (If Diagrammed)	Optional or Mandatory	Estimated Dimensions	Comment
ADT of Major Facility in Zeroth Year	TIM	Mandatory		
ADT of Secondary Facility in Zeroth Year	TIS	See Comment		Mandatory for intersections; optional for other site types.
Percent Compounded Growth Rate of ADT for Major Facility	TMGC	Optional		User must specify ADT growth by one of three methods: Option 1 Site Types 1 and 2: Specify TMGC or TMGL. Site Type 3: Specify TMGC or TMGL and TSCC or TSGL. Option 2 Site Types 1 and 2: Specify ADTM ( ) for each year of the analysis period. Site Type 3: Specify ADTM ( ) and ADTS ( ) for each year of the analysis period Option 3 Set TMGC = TMGL = TSCC = TSGL = 0 for constant ADT during entire analysis period.
Percent Linear Growth Rate of ADT for Major Facility	TMGL	Optional		
Percent Compounded Growth Rate of ADT for Secondary Facility	TSCC	Optional		
Percent Linear Growth Rate of ADT for Secondary Facility	TSGL	Optional		
ADT of Major Facility for Each Year of Analysis Period	ADTM ( )	Optional	(20)	
ADT of Secondary Facility for Each Year of Analysis Period	ADTS ( )	Optional	(20)	
Total Number of Accidents Prior to Countermeasure Implementation	AALL	Mandatory		
Number of Fatal and Injury Accidents Prior to Countermeasure implementation	AFI	Optional		The user should provide values for both AFI and APD0 or for neither. They will be calculated from default values if neither is provided. AFI and APD0 must sum to AALL.
Number of property-damage-only accidents prior to countermeasure implementation.	APD0	Optional		
Number of head-on accidents prior to countermeasure Implementation	AH0	Optional		The user should provide all values for each of AH0, ARE, ASS, ARA, ALT, APR, AF0, APED and A0TH or for none of them. They will be calculated from default values if none of them are provided. These nine variables must sum to AALL.
Number of Rear-End Accidents Prior to Countermeasure Implementation	ARE	Optional		
Number of Side-Swipe Accidents Prior to Countermeasure Implementation	ASS	Optional		
Number of Right-Angle Accidents Prior to Countermeasure Implementation	ARA	Optional		
Number of Left Turn Accidents Prior to Countermeasure Implementation	ALT	Optional		

TABLE 11 (Continued)

Description of Item	Symbol (If Diagrammed)	Optional or Mandatory	Estimated Dimensions	Comment
Number of Parking-Related Accidents Prior to Countermeasure Implementation	APR	Optional		The user should provide all values for each of AHØ, ARE, ASS, ARA, ALT, APR, AFØ, APED, and AØTH or for none of them. They will be calculated from default values if none of them are provided. These nine variables must sum to AALL.
Number of Fixed Object Accidents Prior to Countermeasure Implementation	AFØ	Optional		
Number of Pedestrian Accidents Prior to Countermeasure Implementation	APED	Optional		
Number of Other Accidents Prior to Countermeasure Implementation	AØTH	Optional		
Number of Wet-Pavement Accidents Prior to Countermeasure Implementation	AWET	Optional		The user should provide values for both AWET and ADRY or for neither. They will be calculated from default values if neither is provided. AWET and ADRY must sum to AALL.
Number of Dry-Pavement Accidents Prior to Countermeasure Implementation	ADRY	Optional		
Number of Nighttime Accidents Prior to Countermeasure Implementation	ANIT	Optional		The user should provide values for both ANIT and ADAY or for neither. They will be calculated from default values if neither is provided. ANIT and ADAY must sum to AALL.
Number of Daytime Accidents Prior to Countermeasure Implementation	ADAY	Optional		
Countermeasures (The following input items apply to each countermeasure specified by the user.)				
Countermeasure Number	KM	Mandatory		Must be in appropriate range; see Section VII
Countermeasure Name		Mandatory		Assigned by user
Number of Units of Countermeasure	UN(KM)	Mandatory	(180)	Mandatory for each KM to be evaluated.
Specified Capital Cost Per Unit	SCAPC(KM)	See Comment	(180)	This input is mandatory for nonzero right-of-way costs which are assigned separate subscripts (KM + K2) for countermeasures that may require ROW. When initial base condition is "as planned" resurfaced or rebuilt condition, the cost for the surface course is input as SCAPC(1) per unit. This input is optional for other non-right-of-way unit costs. If used, the logic will employ SCAPC(KM) rather than CAPC(KM) from cost file.

TABLE 11 (Continued)

Description of Item	Symbol (If Diagrammed)	Optional or Mandatory	Estimated Dimensions	Comment
Applied Life (Years) for Countermeasure KM at Site Analyzed	LAF(KM)	See Comment	(180)	Input is mandatory for right-of-way. For non-right-of-way subscripts LAF ( ) is normally calculated and need not be input. However, if LAF ( ) is input, input value will be employed.
Final Capital Worth Per Unit of Countermeasure KM After LAF(KM) Years at Analyzed Site	FCW(KM)	See Comment	(180)	Above comments apply. Also, whenever LAF(KM) is input FCW(KM) <u>must</u> also be read in.
Average Annual Maintenance and Operating Expenses Per Unit of Countermeasure	SCMA0(KM)	Optional	(180)	If SCMA0(KM) is supplied by user, it replaces the value of CMA0(KM) contained in cost files.
Annual Rate of Change of Maintenance and Operating Expenses Per Unit of Countermeasure	SSMA0(KM)	Optional	(180)	If SSMA0(KM) is supplied by user, it replaces the value of CCMA0(KM)contained in cost files.
Upper Bound on Annual Maintenance and Operating Expenses.	SMA0M(KM)	Optional	(180)	If SMA0M(KM) is supplied by user, it replaces the value of CCMA0(KM) contained in cost files. See explanation of CCMA0(KM) in Section V.
Time that Traffic Service is Reduced Due to Construction of Countermeasure on Length ZLGH(KM)	TDUR(KM)	Optional	(180)	Expressed in days. Set TDUR(KM) = 0 if construction of countermeasure KM does not involve reduced traffic service.
Type of Construction Zone Configuration	KZOW(KM)	See Comment	(180)	Mandatory if TDUR(KM) is nonzero. KZOW(KM) 1 for two-lane two-way roadway reduced to one lane and shoulder; = 2 for two lane, two-way roadway reduced to one lane with alternating directions; = 3 for two unidirectional lanes reduced to one lane; = 4 for three unidirectional lanes reduced to two unidirectional lanes; = 5 for three unidirectional lanes reduced to one unidirectional lane; and = 6 for four lane roadway reduced to two-lane, two-way roadway.

TABLE 11 (Continued)

Description of Item	Symbol (If Diagrammed)	Optional or Mandatory	Estimated Dimensions	Comment
Length of Construction Zone	ZLGH(KM)	See Comment	(180)	Mandatory if TDUR(KM) is nonzero. ZLGH(KM) is the length of highway with reduced traffic service.
Code for Construction Schedule	KCSCD(KM)	See Comment	(180)	Mandatory if TDUR(KM) is nonzero. KCSCD(KM) is a code representing the portion of each construction day for which traffic service is reduced. KCSCD(KM) = 1 for 24 hr in urban areas; = 2 with peak hours excluded in urban areas; = 3 for daytime hours only between peak periods in urban areas; = 4 for 24 hr in rural areas; = 5 for daytime hours only between peak periods, rural areas.

(Note: The files contain default values for percent accident reduction for each countermeasure incorporated in the model. The user can override these defaults by specifying the variables given below for five accident breakdowns: all accidents, by severity, by accident type, by pavement condition or by light condition. The user should specify percent reductions for, at most, one of the five accident breakdown options shown below).

Description of Item	Symbol (If Diagrammed)	Optional or Mandatory	Estimated Dimensions	Comment
Percent Reduction for All Accidents	PRALL(KM)	Optional	(180)	Option 1 - Percent reduction for all accidents.
Percent Reduction for Fatal and Injury Accidents	PRFI(KM)	Optional	(180)	Option 2 - Percent reduction by severity.
Percent Reduction for Property Damage Only Accidents	PRPD0(KM)	Optional	(180)	
Percent Reduction for Head-On Accidents	PRH0(KM)	Optional	(180)	Option 3 - Percent reduction by accident type.
Percent Reduction for Rear-End Accidents	PRRE(KM)	Optional	(180)	
Percent Reduction for Side-Swipe Accidents	PRSS(KM)	Optional	(180)	
Percent Reduction for Right-Angle Accidents	PRRA(KM)	Optional	(180)	
Percent Reduction for Left-Turn Accidents	PRLT(KM)	Optional	(180)	
Percent Reduction for Parking-Related Accidents	PRPR(KM)	Optional	(180)	

TABLE 11 (Concluded)

Description of Item	Symbol (If Diagramed)	Optional or Mandatory	Estimated Dimensions	Comment
Percent Reduction for Fixed Object Accidents	PRFØ (KM)	Optional	(180)	
Percent Reduction for Pedestrian Accidents	PRPED(KM)	Optional	(180)	Option 3 - Percent reduction by accident type. (continued)
Percent Reduction for Other Accidents	PRØTH(KM)	Optional	(180)	
Percent Reduction for Wet-Pavement Accidents	PRWET(KM)	Optional	(180)	Option 4 - Percent Reduction by pavement condition.
Percent Reduction for Dry-Pavement Accidents	PRDRY(KM)	Optional	(180)	
Percent Reduction for Night Time Accidents	PRNIT(KM)	Optional	(180)	Option 5 - Percent reduction by light condition.
Percent Reduction for Daytime Accidents	PRDAY(KM)	Optional	(180)	

B. Site Characteristics

This portion of the input data contains several basic site parameters such as the site description, state and region, area type, highway type, site type, site length, fraction of time with wet pavement and average annual precipitation.

The user must specify whether or not a prior decision to resurface the facility has been made and must estimate the remaining life of the facility and the remaining time period before the facility will be resurfaced and/or rebuilt.

The user has the option of specifying the current skid number of the facility. However, default values of skid number are available from the files in the event that the user does not have this information available.

The ADT of the facility in both the zeroth year and each subsequent year must be specified using one of the three options described in the table.

The user must also specify the expected total number of accidents per year for the facility in its present condition. The user may supply a more detailed description of the accident experience, but if additional accident data are not available, the required accident frequencies can be estimated using default accident distributions contained in the program.

C. Countermeasures

The user must specify one or more countermeasures for analysis by the program. Usually, the user will desire to compare several options for reduction of accidents at a given site. The only information that the user must supply concerning each countermeasure are the countermeasure number, countermeasure name, number of units of the countermeasure to be installed and a code representing the vulnerability of the countermeasure to resurfacing and rebuilding. However, the user also has the option of replacing the values of applied life, salvage value, capital costs and maintenance and operating costs available from the files.

The model has the capability of including, in the economic analysis, the user costs for delay time and excess fuel consumption due to reduced traffic service during construction of the countermeasure. Four variables must be identified by the user to exercise this option: (1) the number of days when traffic service is reduced due to construction, (2) the type of construction zone configuration, (3) the length of the construction zone and (4) the hours of the day during which traffic service is reduced. This option can be bypassed by setting the number of days with reduced traffic service equal to zero.

Finally, the user can replace the percent accident reductions incorporated in the model (see Section VI.E), by specifying the percent accident reductions for one of five accident breakdowns: all accidents, accidents by severity, accidents by accident type, accidents by pavement conditions or accidents by light condition.

IX. SUMMARY OF OUTPUT

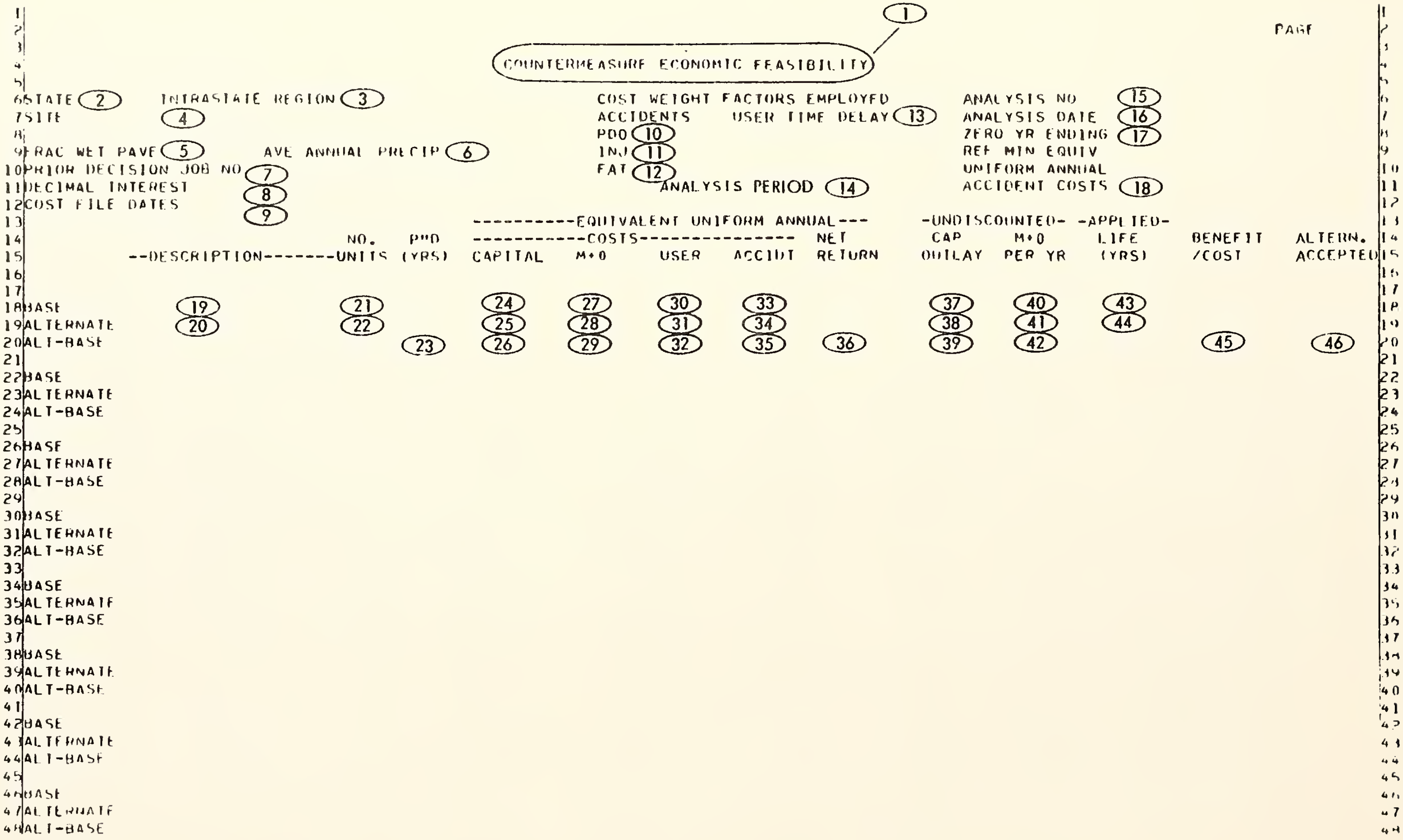
The computer program provides a printed output for each case that is analyzed. This output presents all of the economic data required by a highway engineer or administrator to make planning and budgeting decisions, and the output will serve as a permanent record of the analysis results. This section of the report presents the output formats used by the model and explains all of the output data.

The input data supplied by the user is printed in an expanded card format. This output is very important since it will contain the numerical information where the user has overridden standard file values.

The benefit-cost model produces output in two forms corresponding to the two stages of the benefit-cost analysis: countermeasure economic feasibility analysis and project formulation. The difference between these stages, as explained in Section IV.B, is that in the economic feasibility analysis each alternate countermeasure is compared with the initial base condition, while in the project formulation stage the countermeasures are compared incrementally, in order of increasing capital costs. When a countermeasure is accepted in project formulation (incremental benefit/cost ratio greater than one), it becomes the base for subsequent calculations. Since the economic data that must be presented are similar, the headings and printout formats used for each stage of the analysis are identical, except for the main heading at the top of each page. The output from the economic feasibility and project formulation analyses are presented on consecutive printout pages.

Figure 8 illustrates the output format that is used for both economic feasibility and project formulation. Lines 1 through 12 of the printout are a heading block containing general information identifying the analysis site and the type of analysis. Beginning with line 18, the printout is organized into groups of three lines labeled BASE, ALTERNATE and ALT-BASE. Each group of lines represents a comparison between one alternate coutermeasure and the appropriate base condition. In each stage of the analysis, these groups of three lines are repeated as many times as necessary to compare each alternative with the appropriate base condition. As an example, consider lines 18 to 20, the first group shown in Figure 8. All cash flows for the base and alternate condition are listed on lines 18 and 19, respectively. Line 20 contains the differences between these cash flows, expressed as the cash flow for the alternate minus the cash flow for the base.

The data items presented on the output are numbered 1 through 46 in Figure 8. Each of these items is discussed below in detail.



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                                                                         ①
                                                                                                           PAGE
                                          COUNTERMEASURE ECONOMIC FEASIBILITY

STATE ②      INTRASTATE REGION ③                        COST WEIGHT FACTORS EMPLOYED        ANALYSIS NO     ⑮
SITE          ④                                          ACCIDENTS      USER TIME DELAY ⑬   ANALYSIS DATE   ⑯
                                                         PDO ⑩                               ZERO YR ENDING  ⑰
FRAC WET PAVE ⑤      AVE ANNUAL PRECIP ⑥                INJ ⑪                               REF MIN EQUIV
PRIOR DECISION JOB NO ⑦                                  FAT ⑫                               UNIFORM ANNUAL
DECIMAL INTEREST      ⑧                                      ANALYSIS PERIOD ⑭               ACCIDENT COSTS  ⑱
COST FILE DATES       ⑨
                                          ----------EQUIVALENT UNIFORM ANNUAL---    -UNDISCOUNTED- -APPLIED-
                                 NO.   P"D    -----------COSTS--------------  NET        CAP     M+0     LIFE     BENEFIT   ALTERN.
     --DESCRIPTION-------UNITS (YRS)  CAPITAL    M+0    USER   ACCIDT  RETURN     OUTLAY  PER YR   (YRS)    /COST     ACCEPTED


BASE          ⑲            ㉑          ㉔       ㉗      ㉚      ㉝                 ㊲      ㊵       ㊸
ALTERNATE     ⑳            ㉒          ㉕       ㉘      ㉛      ㉞                 ㊳      ㊶       ㊹
ALT-BASE                         ㉓   ㉖       ㉙      ㉜      ㉟      ㊱         ㊴      ㊷                  ㊺          ㊻

BASE
ALTERNATE
ALT-BASE

BASE
ALTERNATE
ALT-BASE

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ALT-BASE

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ALTERNATE
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ALT-BASE

BASE
ALTERNATE
ALT-BASE
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Figure 8 - Format of Printed Output

A. Heading Block

The following information is presented in the heading at the beginning of each stage of the analysis.

Item 1 - Main Heading. The heading COUNTERMEASURE ECONOMIC FEASIBILITY or PROJECT FORMULATION appears at the top of the page to identify the stage of the analysis for which results are presented.

Item 2 - State. This item is a two-character code identifying the state in which analysis site is located. This code, whose computer symbol is KSTAT, is assigned by the user as input data.

Item 3 - Intrastate Region. This item is a two-character code identifying a region within the state in which the analysis site is located. This code, whose computer symbol is KSTAR, is assigned by the user as input data.

Item 4 - Analysis Site. This space on the printout is reserved for the name or description of the analysis site, as specified by the user. It appears on the printout on two lines, with a maximum of 40 characters on each line.

Item 5 - Fraction of Wet-Pavement Time. This item is the fraction of time with wet pavement at the analysis site and is specified by the user as input. The computer symbol for this fraction is FWET.

Item 6 - Average Annual Precipitation. The average annual precipitation for the region in which the analysis site is located is printed in space 6. This quantity is specified by the user as input and is represented in the computer by the symbol APREC.

Item 7 - Prior-Decision Job Number. If a prior decision has been made to resurface or rebuild the facility, the job number assigned by the user for that decision will appear in space 7. Thus, if a job number appears here, it indicates that the benefit-cost analysis has included the impact of the prior decision. If no prior-decision job number appears, then the facility has been analyzed in its present condition. A complete discussion of the treatment of prior decisions in the model is found in Section V.H of this report.

Item 8 - Decimal Interest Rate. The interest or vestcharge rate used in the analysis is presented here in decimal form. This quantity, represented in the computer by the symbol V, is the minimum rate of return that is acceptable to the user.

Items 10, 11, 12 and 13 - Cost Weight Factors. The items presented here are the weight factors for costs of property damage only accidents, injury accidents, fatal accidents and user time delay, respectively. These variables have a default value of 1.0, which is used unless the user specifies some other value. The cost weight factors are displayed on the output to provide a permanent record of any adjustments made during the analysis to the costs obtained from the cost files. See Section V.J for a description of these factors.

Item 14 - Length of Analysis Period. This space contains the label LONG or SHORT to identify whether the longer or shorter analysis period has been used when countermeasures with unequal service lives are compared. As stated in Section V.D, the choice of analysis periods is determined by the value of the variable JPER( ). In the default case, the program sets JPER( ) = 2 and uses the longer of the two analysis periods. The user has the option of setting JPER( ) = 1 and using the shorter analysis period, or of performing the analysis twice, using each of the two periods.

Item 15 - Analysis Number. The analysis number is a 14-digit number of the form: XX XX XXXX XXXXXX. The first two digits of the analysis number identify the state in which the analysis site is located. The next two digits identify the appropriate region within that state. The next four digits identify the year in which the analysis was conducted, and the final six digits are a sequence number assigned to the analysis. The analysis number is intended as a unique designation that can be used to identify the particular analysis in a state's file.

Item 16 - Analysis Date. This item is the month, day and year on which the analysis was conducted. It is the form: XX XX XXXX where the first two digits represent the month (01 = January,..., 12 = December), the next two digits represent the day (01,..., 31), and the final four digits represent the year (1977, 1978, 1979, etc.).

Item 17 - Date Zeroth Year Ends. This item is the final date of the zeroth year of the analysis. The zeroth year is the year during which the countermeasure is implemented. This date is specified by the user as input and is presented in the same format as Item 16.

Item 18 - Minimum Equivalent Uniform Annual Accident Cost. The minimum equivalent uniform annual accident cost is not incorporated in the current version of the model, but a space is reserved for it on the output should it be added in a subsequent revision. This quantity represents the lowest total accident cost that would be possible if the most effective available countermeasure were implemented. This quantity will be used in Subroutine SIG to determine whether any significant accident savings are possible at the analysis site.

B. Comparisons of Base and Alternate Conditions

Cash flows and other relevant data for the each pair of base and alternate conditions analyzed are presented on the printout lines labeled BASE and ALTERNATE. The differences between these cash flows are used in the calculation of benefit/cost ratio and are presented on the line, ALT-BASE. The following discussion describes each item found on these three lines.

Items 19 and 20 - Countermeasure Description. These spaces contain 20 character titles identifying the countermeasures compared on the lines. The user specifies a name for each countermeasure selected as input to the model. In the economic feasibility stage, the base case will always be the present condition of the facility (or its projected condition based on prior decisions), and will be identified in item 19 by the designation EXISTING. The alternate will be a user-selected countermeasure with a user-selected name. In the project formulation stage, the base will be the least expensive countermeasure, but the initial base may be replaced by a more cost-beneficial countermeasure as the incremental analysis proceeds.

Items 21 and 22 - Number of Countermeasure Units. Items 21 and 22 identify the number of units of each countermeasure required for the base and alternate cases. These values are specified by the user and their units must be compatible with the unit costs available in the cost files. The numbers of units are used to determine the capital cost of each countermeasure from the cost files. When the existing condition is used as the base, item 21 will be zero, but in all other situations items 21 and 22 are non-zero. The computer symbols for items 21 and 22 are UN(KB) and UN(KC), respectively.

Item 23 - Period of Analysis. This data item is the period of analysis (in years) that is used to compare the base and alternate conditions. It is printed on the third (ALT-BASE) line and its computer symbol is IA. The period of analysis is determined by the program for each base and alternate countermeasure, and depends on their normal service lives and on the user's selection of the long or short option for length of analysis period.

Items 24, 25 and 26 - Equivalent Uniform Annual Capital Costs. Items 24 and 25 are the equivalent uniform annual capital costs for the base and alternate conditions, respectively. These are determined by annualizing all capital expenditures for each countermeasure. The equivalent uniform annual capital cost for the existing condition is zero except in two cases. First, if a prior decision has been made to resurface (or to resurface as part of rebuilding), the capital cost for the resurfacing appears in the base case when an alternative resurfacing countermeasure is evaluated in economic feasibility. If the alternative surface is accepted, its capital costs in subsequent calculations for project formulation are reduced in accord with the capital commitment from the prior decision.

In the second situation, base case capital costs will appear in economic feasibility calculations when a resurfacing countermeasure would last longer than the existing surface course. In this situation, the future capital cost of the base case resurfacing is discounted and distributed over the entire period until its end of life. There is no influence in project formulation calculations.

Item 26 is the difference between the equivalent uniform annual capital costs for the alternate and base conditions and is used as the denominator of the benefit/cost ratio. The computer symbols for these three capital costs are UCC(1), UCC(2), and UCC(3), respectively.

Items 27, 28 and 29 - Equivalent Uniform Annual Maintenance and Operating Costs. The meanings of these costs are directly analogous to the capital costs discussed above, except that they represent the maintenance and operating costs. The maintenance and operating costs are always non-zero, even for the existing condition. The computer symbols for items 27, 28 and 29 are EUAM0(1), EUAM0(2), and EUAM0(3), respectively.

Items 30, 31 and 32 - Equivalent Uniform Annual User Costs. The meanings of these costs are directly analogous to the maintenance and operating costs discussed above, except that they represent user costs associated with construction or other implementation. The computer symbols for items 30, 31 and 32 are EUAUC(1), EUAUC(4) and EUAUC(3), respectively.

Items 33, 34 and 35 - Equivalent Uniform Annual Accident Costs. The meanings of these costs are directly analogous to the maintenance and operating costs discussed above except that they represent the cost of traffic accidents at the analysis site. The computer symbols for items 33, 34 and 35 are EUAAC(1), EUAAC(2) and EUAAC(3), respectively.

Item 36 - Net Return. This quantity is the sum of the equivalent uniform annual costs shown on the ALT-BASE line for capital outlays, maintenance and operating costs, user costs and accident costs. The net return is represented in the computer program by the symbol RN.

Items 37, 38 and 39 - Undiscounted Capital Outlays. Items 37 and 38 are the undiscounted capital costs for the base and alternate conditions. Each of these quantities is the sum of the values of all capital outlays at the time they occur. When the only capital outlay occurs during the zeroth year, these quantities are simply the present value of the equivalent uniform annual capital costs given in items 24 and 25. Item 39 is the difference between the undiscounted capital outlays for the alternate and base conditions. The computer symbols for items 37, 38 and 39 are C0LD(1), C0LD(2), and C0LD(3), respectively.

Items 40, 41 and 42 - Undiscounted Average Maintenance and Operating Expenses. Items 40 and 41 are the average undiscounted maintenance and operating expenses per year for the entire analysis period for the base and alternate conditions. These items are the sums of all maintenance and operating expenditures during the analysis period divided by the number of years in the analysis period. Item 42 is the difference between items 41 and 40. The computer symbols for items 40, 41 and 42 are AMØ(1), AMØ(2) and AMØ(3), respectively.

Items 43 and 44 - Applied Lives of Countermeasures. These spaces contain the applied lives for the base and alternate conditions. The applied life of a countermeasure can differ from the normal service life, as explained in Section V.D. The computer symbols for Items 43 and 44 are LAF(KB) and LAF(KC), respectively.

Item 45 - Benefit/Cost Ratio. The benefit/cost ratio, represented by the computer symbol BCR(KC), is formed from the equivalent uniform annual cash flows shown on the printout, using the definition presented in Section V.B.

Item 46 - Acceptance of Alternatives. If the benefit/cost ratio is larger than 1.0, the alternate is accepted and YES is printed on the output. If the benefit/cost ratio is smaller than 1.0, the alternate is rejected and NO is printed. In the economic feasibility stage, acceptance of an alternate countermeasure means that the alternate is preferable to the existing condition and should be included in the project formulation state. If a countermeasure is rejected in the economic feasibility stage, it is not considered further. If an alternate is accepted in the project formulation stage, it becomes the new base to which subsequent alternates are compared. The last alternate for which a YES is found in the acceptance of alternatives column on the project formulation printout is the best investment of capital.

X. EXAMPLE OF BENEFIT-COST ANALYSIS

This section of the report presents the solution of an example problem using the benefit-cost model. Section A explains the example problem to be solved. The problem presented is completely hypothetical, but is typical of the kinds of problems that can be solved using the model. Section B presents the values of all input variables to the model including both the data supplied by the user and data obtained from the files. The outputs from the economic feasibility and project formulation stages of the analysis are presented in Section C.

A. Example Problem

A state highway department has identified the 2-mile portion of State Route 55 between Mileposts 15.0 and 17.0 as one of several highway sections in the state with adverse accident experience resulting from low skid resistance, among other causes. Route 55 is a two-lane rural highway whose current ADT of 5,000 is expected to increase at a linear rate of 3% per year. The pavement currently has a skid number at 40 mph of 32.0. The section is exposed to wet-pavement conditions 25% of the time, on the average. The section currently experiences 19 accidents per year, corresponding to an accident rate of 5.21 accidents per million vehicle-miles.

The state is considering three alternate countermeasures to reduce the accident experience for this highway. The first countermeasure, designated as countermeasure number 2, is to resurface the section with a normal asphalt concrete surface course. Normal resurfacing is assumed to cost $12,500 per mile and will initially increase the skid number at 40 mph to 66.0. The skid number will decrease with traffic wear after installation according to the following relationship:[30]

$$SN = 66.0 - 8.3\ \ell n\ (CT/10^5)$$

where SN = Skid number at 40 mph, and

CT = Cumulative number of vehicle passes,

until reaching a constant final value of 25.0.

The second countermeasure, designated countermeasure Number 3, consists of resurfacing with a special asphalt concrete surface course using 50% lightweight aggregate. The advantage of the special surface course is its superior skid resistance qualities. Special resurfacing is assumed to cost $20,000 per mile and will initially increase the skid number at 40 mph to 43.0. However, the skid number will increase from its initial value, rather than decrease, with traffic exposure. The relationship for the increase of skid number at 40 mph for the special surface course is:[43-44]

$$SN = 43.0 + 2.428 \ln (CT/10^5)$$

with a maximum SN of 70.0

The final countermeasure is the improvement of warning signs on the section, designated as countermeasure number 28 in Table 5. State highway engineers have determined that this countermeasure would require improvement of 16 signs at $200 per sign.

It is assumed that both of the resurfacing countermeasures can be constructed in 4 working days. The lanes in each direction at a time will be closed for 1/2 day at each of four 0.5 mile work sites with traffic operating in alternating directions in the other lane. The reduction in traffic service will begin each day at 8 AM and cease at 4 PM. User delay time is estimated at $3.00 per hour and gasoline costs at $0.60 per gal. Installation of warning signs will not involve any reduction in traffic service.

The resurfacing countermeasures have normal service lives of 15 years, while the warning signs have service lives of 5 years. It is assumed that no resurfacing or rebuilding will interrupt these service lives and that none of the countermeasures has any salvage value at the end of its useful life. It is also assumed that the user elects the longer period of analysis when countermeasures with different service lives are compared. Finally, it is assumed that this highway section costs $500 per mile per year to maintain and that none of the countermeasures influence this maintenance cost.

B. Input Data for Example Problem

The user should begin the solution of a problem by specifying the values for the input variables. Table 12 presents the values of the input variables for the example problem presented above. Definitions of these variables are presented in Sextion VIII of this report. Table 12 includes all variables that can be used as input to the program. The reader will note that many of the input variables have a value of zero. These variables can be used to supercede default variables contained in the system files. In this example, we have elected to use the default values in the system files. Therefore, zero values have been indicated at appropriate places in Table 12. In actual practice a zero or a blank could be input for these variables. In this example, we have elected to use the default values in the system files. In addition, most of these variables are contained on optional input cards that do not need to be used each time the program is run if all input variables on the card are zero or blank.

Table 13 presents a partial list of the values of input variables obtained by the program from the system files in solving the example problem. Definitions of each of these variables are contained in Appendix G.

TABLE 12

INPUT DATA SUPPLIED BY USER FOR EXAMPLE PROBLEM

Data Item	Symbol	Value
Sequence Number		028964
Analysis Date		01 31 1977
End Date of Zeroth Year		12 31 1978
Decimal Interest Rate	V	0.06
Subscript for Following Five Codes	NVAR	1
Weight Factor for Property-Damage-Only Accident Costs	FPD(NVAR)	Default Value = 1
Weight Factor for Injury Accident Costs	FIA(NVAR)	Default Value = 1
Weight Factor for Fatal Accident Costs	FFA(NVAR)	Default Value = 1
Weight Factor for User Delay Costs	FUTC(NVAR)	Default Value = 1
Code for Analysis Period	JPER(NVAR)	Default Value = 2
Upper Limit on Period of Analysis (Years)	MXYR	Default Value = 20
Coefficient for Fraction of Accident Costs Saved in Test for Significant Savings	CCAS	0
Coefficient for Fraction of Accident Costs Saved in Test for Significant Savings	CFAS	0
Site Description		STATE ROUTE 55 MP 15.0-17.0
Numerical Code for State	KSTAT	01
Numerical Code for Region	KSTAR	01
Area Type	IATYP	1
Highway Type	IHTYP	1
Site Type	ISITE	1
Site Length (miles)	TLGH	2.00
Fraction of Time with Wet Pavement	FWET	0.25
Average Annual Precipitation (in.)	APREC	52.0
Code for Prior Decision to Resurface	IRS	0
Prior Decision Job Number		
Number of Units of Surface Course Planned as a Result of Prior Decision	UN(1)	0
Final Capital Worth per Unit of Surface Course Planned as a Result of Prior Decision	FCW(1)	0
Normal Remaining Life of Facility	LIFF	25
Number of Years Until Scheduled Rebuilding	LIFRB	15
Number of Years Unit Scheduled Resurfacing	LIFRS	15
Current Skid Number	SNY0	32.0
Current or Planned Surface Type	KWS	2
ADT for Majority Facility in Zeroth Year	TIM	5000

TABLE 12 (continued)

Data Item	Symbol	Value
ADT for Secondary Facility in Zeroth Year	TIS	0
Percent Compounded Growth Rate of ADT for Major Facility	TMGC	0
Percent Linear Growth Rate of ADT for Major Facility	TMGL	3
Percent Compounded Growth Rate of ADT for Secondary Facility	TSGC	0
Percent Compounded Growth Rate of ADT for Secondary Facility	TSGL	0
ADT of Major Facility in Each Year	ADTM( )	ALL = 0
ADT of Secondary Facility in Each Year	ADTS( )	ALL = 0
Total Number of Accidents	AALL	19
Total Number of Fatal and Injury Accidents	AFI	0
Total Number of Property-Damage-Only Accidents	APD0	0
Total Number of Head-On Accidents	AH0	0
Total Number of Rear-End Accidents	ARE	0
Total Number of Side-Swipe Accidents	ASS	0
Total Number of Right-Angle Accidents	ARA	0
Total Number of Left-Turn Accidents	ALT	0
Total Number of Parking-Related Accidents	APR	0
Total Number of Fixed-Object Accidents	AF0	0
Total Number of Pedestrian Accidents	APED	0
Total Number of Other Accidents	A0TH	0
Total Number of Wet-Pavement Accidents	AWET	0
Total Number of Dry-Pavement Accidents	ADRY	0
Total Number of Nighttime Accidents	ANIT	0
Total Number of Daytime Accidents	ADAY	0

Data Item	Symbol	Value		
		KM=2	KM=3	KM=28
Countermeasure Number	KM	2	3	28
Countermeasure Name		NORMAL RESURFACING	SPECIAL RESURFACING	WARNING SIGNS
Number of Units of Countermeasure	UN(KM)	2.0	2.0	16.0
User-Supplied Capital Outlay Per Unit of Countermeasure	SCAPC(KM)	0	0	0
Applied Life of Countermeasure	LAF(KM)	0	0	0
Final Capital Worth of Countermeasure After LAF(KM) Years	FCW(KM)	0	0	0

TABLE 12 (continued)

Data Item	Symbol	Value KM=2	 KM=3	 KM=28
User-Supplied Maintenance and Operating Expenses Due to Countermeasure	SCAMØ(KM)	0	0	0
User-Supplied Annual Rate of Change of Maintenance and Operating Expenses	SSMAØ(KM)	0	0	0
User-Supplied Upper Bound on Maintenance and Operating Expenses	SMAØM(KM)	0	0	0
Time When Traffic Service is Reduced Due to Countermeasure Construction on Length ZLGH(KM)	TDUR(KM)	1	1	0
Type of Construction Zone Configuration	KZOW(KM)	2	2	0
Length of Construction Zone	ZLGH(KM)	0.5	0.5	0
Code for Construction Schedule	KCSCD(KM)	5	5	0
Percent Reduction for All Accidents	PRALL(KM)	0	0	0
Percent Reduction for Fatal and Injury Accidents	PRFI(KM)	0	0	0
Percent Reduction for Property-Damage-Only Accidents	PRPDØ(KM)	0	0	0
Percent Reduction for Head-On Accidents	PRHØ(KM)	0	0	0
Percent Reduction for Rear-End Accidents	PRRE(KM)	0	0	0
Percent Reduction for Side-Swipe Accidents	PRSS(KM)	0	0	0
Percent Reduction for Right-Angle Accidents	PRRA(KM)	0	0	0
Percent Reduction for Left-Turn Accidents	PRLT(KM)	0	0	0
Percent Reduction for Parking Related Accidents	PRPR(KM)	0	0	0
Percent Reduction for Fixed-Object Accidents	PRFØ(KM)	0	0	0
Percent Reduction for Pedestrian Accidents	PRPED(KM)	0	0	0
Percent Reduction for Other Accidents	PRØTH(KM)	0	0	0

TABLE 12 (concluded)

Data Item	Symbol	Value KM=2	 KM=3	 KM=28
Percent Reduction for Wet-Pavement Accidents	PRWET(KM)	0	0	0
Percent Reduction for Dry-Pavement Accidents	PRDRY(KM)	0	0	0
Percent Reduction for Night-time Accidents	PRNIT(KM)	0	0	0
Percent Reduction for Day-time Accidents	PRDAY(KM)	0	0	0

TABLE 13

PARTIAL LIST OF DATA FROM SYSTEM FILES FOR EXAMPLE PROBLEM

Data Item	Symbol	Value
Cost File Dates		09 01 1976
Average Number of Vehicles Per Property-Damage-Only Accident	AP1(1)	1.71
Average Number of Injuries Per Injury Accident	AP2(1)	1.66
Average Number of Fatalities Per Fatal Accidents	AP3(1)	1.22
Cost of Property-Damage-Only Accident Per Involved Vehicle	CT1	300
Cost Per Injury	CT2	7300
Cost Per Fatality	CT3	200700
Cost Per Vehicle-Hour of Delay	CVHD	3
Cost Per Gallon of Fuel	CFUEL	0.60
Average Fuel Consumption (gal/vehicle-hr) at Idle	CIDLE	0.0376
Average Annual Maintenance and Operating Cost Per Mile in Area Type IATYP and Highway Type IHTYP	ACMA0(1,1)	500
Percent of All Accidents Which are Fatal and Injury Accidents	PFI(1,1,1)	36.91
Percent of All Accidents Which are Property-Damage-Only Accidents	PPD0(1,1,1)	63.09
Average Skid Number for Area Type IATYP	SBAR(1)	46.0
Expected Increase in Accident Rate During Countermeasure Construction	ADR	1.068

Data Item	Symbol	Value		
		KM=2	KM=3	KM=28
Site Type for Which Geometric or Traffic Control Countermeasure Was Evaluated	JSITE(KM)	0	0	1
Area Type for Which Geometric or Traffic Control Countermeasure Was Evaluated	JATYP(KM)	0	0	1
Highway Type for Which Geometric or Traffic Control Countermeasure Was Evaluated	JHTYP(KM)	0	0	1
Fraction of Time Pavement Were Wet at Site Where Geometric or Traffic Control Countermeasures Were Evaluated	CAPFW(KM)	0	0	0.13
Normal Life (years) of Countermeasure	LIFC(KM)	15	15	5
Code for Vulnerability to Resurfacing and Rebuilding	TRL(KM)	2.10	2.00	1.99
Standard Capital Outlay Per Unit for Countermeasure	CAPC(KM)	12500	20000	200
Net Salvage Value Per Unit of Countermeasure	SALV(KM)	0	0	0
Maintenance and Operating Expense Due to Countermeasure	CMA0(KM)	0	0	0

TABLE 13 (concluded)

Data Item	Symbol	Value		
		KM=2	KM=3	KM=28
Rate of Change of Maintenance and Operating Expenses	CCMA0(KM)	0	0	0
Upper Bound on Maintenance and Operating Expenses	CMA0M(KM)	0	0	0
Skid Number Immediately After Resurfacing	SD0R(KM)	66	43	0[a]
Coefficient for Rate of Change of Skid Number with Traffic Passages	CSR(KM)	-8.3	2.428	0[a]
Final Value of Skid Number	SDFR(KM)	25	70	0[a]
Default Percent Reduction for All Accidents	DPRALL(KM)	0	0	36
Default Percent Reduction for Fatal and Injury Accidents	DPRFI(KM)	0	0	32
Default Percent Reduction for Property-Damage-Only Accidents	DPRPD0(KM)	0	0	38
Default Percent Reduction for Head-On Accidents	DPRH0(KM)	0	0	0
Default Percent Reduction for Rear-End Accidents	DPRRE(KM)	0	0	0
Default Percent Reduction for Side-Swipe Accidents	DPRSS(KM)	0	0	0
Default Percent Reduction for Right-Angle Accidents	DPRRA(KM)	0	0	0
Default Percent Reduction for Left-Turn Accidents	DPRLT(KM)	0	0	0
Default Percent Reduction for Parking-Related Accidents	DPRPR(KM)	0	0	0
Default Percent Reduction for Fixed-Object Accidents	DPRF0(KM)	0	0	0
Default Percent Reduction for Pedestrian Accidents	DPRPED(KM)	0	0	0
Default Percent Reduction for Other Accidents	DPR0TH(KM)	0	0	0
Default Percent Reduction for Wet-Pavement Accidents	DPRWET(KM)	0	0	0
Default Percent Reduction for Dry-Pavement Accidents	DPRDRY(KM)	0	0	0
Default Percent Reduction for Nighttime Accidents	DPRNIT(KM)	0	0	0
Default Percent Reduction for Daytime Accidents	DPRDAY(KM)	0	0	0

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[a] The input value of SD0R(28) is shown as zero. This value is not used for geometric and traffic control countermeasures. The program will define SD0R(28) as equal to SD0R(2) because the current surface type, KWS, is 2 for this example. The values for CSR(28) and SDFR(28) are treated in a similar manner.

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                                                                                                                    PAGE 1

                                        COUNTERMEASURE ECONOMIC FEASIBILITY

STATE  01      INTRASTATE REGION 01                  COST WEIGHT FACTORS EMPLOYED          ANALYSIS NO  01 01 1977 028964
SITE  STATE ROUTE 55                                 ACCIDENTS     USER TIME DELAY 1.0     ANALYSIS DATE  01 31 1977
    NP 15.0-17.0                                     PDO 1.0                               ZERO YR ENDING 12 31 1978
FRAC WET PAVE 0.25       AVE ANNUAL PRECIP  52.0     INJ 1.0                               REF MIN EQUIV
PRIOR DECISION JOB NO                                FAT 1.0                               UNIFORM ANNUAL
DECIMAL INTEREST  0.05                                     ANALYSIS PERIOD   LONG          ACCIDENT COSTS
COST FILE DATES  09 01 1976
                                              -----------EQUIVALENT UNIFORM ANNUAL---     -UNDISCOUNTED- -APPLIED-
                                    NO.  PRD  -----------COSTS----------------- NET       CAP      M+O     LIFE      BENEFIT   ALTERN.
           --DESCRIPTION---------UNITS (YRS)  CAPITAL    M+O      USER   ACCIDT  RETURN    OUTLAY  PER YR  (YRS)     /COST     ACCEPTED


BASE        EXISTING                               0    1000        0   196323                  0    1000
ALTERNATE   WARNING SIGNS             16         760    1000        0   135652               3200    1000     5
ALT-BASE                                    5    760       0        0   -60671   59911      3200       0               79.864     YES

BASE        EXISTING                               0    1000        0   219893                  0    1000
ALTERNATE   NORMAL RESURFACING         2        2574    1000      107   217129              25000    1000    15
ALT-BASE                                   15   2574       0      107    -2764      83     25000       0                1.032     YES

BASE        EXISTING                               0    1000        0   219893                  0    1000
ALTERNATE   SPECIAL RESURFACING        2        4119    1000      107   195821              40000    1000    15
ALT-BASE                                   15   4119       0      107   -24072   19849     40000       0                5.819     YES

BASE
ALTERNATE
ALT-BASE

BASE
ALTERNATE
ALT-BASE

BASE
ALTERNATE
ALT-BASE

BASE
ALTERNATE
ALT-BASE

BASE                        Figure 9 - Output from Economic Feasibility Stage for Example Problem
ALTERNATE
ALT-BASE
```

Figure 9 - Output from Economic Feasibility Stage for Example Problem

C. Output Data for Example Problem

Figure 9 illustrates the output data from the economic feasibility stage of the analysis. Three sets of benefit-cost calculations are shown. Each countermeasure is compared with the existing condition to determine if it is economically feasible. Each countermeasure was found to have a benefit/cost ratio greater than one, and is, therefore, economically feasible. However, the benefit/cost ratios for the three countermeasures are markedly different. Countermeasure 28, installation of warning signs, has the highest benefit/cost ratio, 79.86 ; countermeasure number 2, normal resurfacing, has the lowest benefit/cost ratio, 1.032. Because all three countermeasures have benefit/cost ratios greater than one, all three are included in the project formulation stage.

The output from the project formulation stage is illustrated by Figure 10. First, the least expensive project, installation of warning signs, is compared with the next-to-least expensive project, normal resurfacing. A benefit/cost ratio of less than one resulted, indicating that installation of warning signs is more cost beneficial than normal resurfacing. The process was repeated to compare installation of warning signs with special resurfacing. Again, installation of warning signs was preferable. Therefore, the conclusion of the analysis is that installation of warning signs is the most appropriate countermeasure for this site, because both of the more expensive countermeasures have incremental benefit/cost ratios less than one.

This conclusion and the cost and benefit data presented on the printouts should be considered by the state highway department, together with other available information, such as legal opinions, in making the final decision on which countermeasure to implement at this site.

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                                                                                                                      PAGE
                                                    PROJECT  FORMULATION

STATE  01      INTRASTATE REGION 01                             COST WEIGHT FACTORS EMPLOYED         ANALYSIS NO  01 01 1977 028964
SITE  STATE ROUTE 55                                            ACCIDENTS     USER TIME DELAY 1.0    ANALYSIS DATE  01 31 1977
      MP 15.0 - 17.0                                            PDO 1.0                              ZERO YR ENDING 12 31 1978
FRAC WET PAVE  0.25      AVE ANNUAL PRECIP 52.0                 INJ 1.0                              REF MIN EQUIV
PRIOR DECISION JOB NO                                           FAT 1.0                              UNIFORM ANNUAL
DECIMAL INTEREST 0.05                                                 ANALYSIS PERIOD   LONG         ACCIDENT COSTS
COST FILE DATES 09 01 1976
                                                ----------EQUIVALENT UNIFORM ANNUAL---    -UNDISCOUNTED-  -APPLIED-
                                   NO.    PUD   -----------COSTS---------------  NET      CAP      M+O     LIFE     BENEFIT    ALTERN.
           --DESCRIPTION-------UNITS (YRS)    CAPITAL   M+O    USER    ACCIDT  RETURN    OUTLAY   PER YR  (YRS)    /COST      ACCEPTED

BASE       WARNING SIGNS         16              760    1000       0   152408             3200     1000      5
ALTERNATE  NORMAL RESURFACING     2             2574    1000     107   217129            25000     1000     15
ALT-BASE                                15      1814       0     107    64720  -66642    21800        0              -35.729      NO

BASE       WARNING SIGNS         16              760    1000       0   152408             3200     1000      5
ALTERNATE  SPECIAL RESURFACING    2             4119    1000     107   195821            40000     1000     15
ALT-BASE                                15      3359       0     107    43413  -46879    36800        0              -12.957      NO

BASE
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ALT-BASE
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Figure 10 - Output from Project Formulation Stage for Example Problem

XI. TESTS OF THE COMPUTERIZED MODEL

Many of the basic concepts and relationships for the model were incorporated into the model before the results from Phase I were available. That initial logic and programming was tested by using simple analytical expressions for the subroutines that were not yet available. Ten cases were calculated manually and all the associated input and expected output were provided to FHWA's Data Systems Division. The 10 cases tested the features and options shown in Table 14. These preliminary tests demonstrated that the overall logic that controls the economic feasibility and project formulation stages operates properly.

At the completion of Phase I, extensive logic was added to the program to incorporate the wet-pavement accident rate-skid number relationships and the changes of skid number with traffic wear. This new logic has been tested by FHWA using the example in Section X and found to operate properly.

There are a large number of logical branches within the program. The example problem tests only a limited number of these branches. A systematic effort is needed to test every branch of the program to assure that all model capabilities are operating properly. Interested users should contact the FHWA Data Systems Division to determine the status of model testing.

TABLE 14

FEATURES AND OPTIONS CHECKED IN PRELIMINARY TESTS

Test No.	1	2	3	4	5	6	7	8	9	10
Project Formulation										
Not Required	x									x
Required		x	x	x	x	x	x	x	x	
Single Case Run										
With one variation	x	x	x	x	x	x	x	x	x	
With multiple variations										x
Multiple Case Run										
Applied Life										
Not specified in input										
Normal service life	x	x	x	x	x					
Terminated by resurface				x						
Terminated by rebuild			x	x	x	x				
Terminated by abandonment							x	x	x	x
Specified in input										x
Final capital worth										
Not specified in input										
Normal salvage	x	x	x	x	x	x				
Possible recovery of service										
Leading to normal salvage										
Leading to recovery of service value			x	x	x	x	x	x	x	x
Specified in input										x
Period of Analysis										
Unequal lives										
Standard (long period) default	x	x	x	x	x	x	x	x	x	x
Short period										x
Equal lives										
Prior Decision to Resurface										
Countermeasure involving resurface							x	x	x	x
Countermeasure not involving resurface							x	x	x	x
Right-of-Way Costs										
Nonzero Row cost										
Row Req. for future rebuild						x				
Row not required for future rebuild					x					
Zero Row Cost			x	x						

TABLE 14 (Concluded)

Test No.	1	2	3	4	5	6	7	8	9	10
Capital Cost										
From file	x	x	x	x	x	x	x	x	x	x
Read in input										x
ADT										
Calculated from coefficient	Constant ⟶							x		
Read in input									x	x
Cost Weight Factors										
Standard default values	x	x	x	x	x	x	x	x	x	x
Non standard (read in)										x
Vestcharge (or Interest) Rate										
From file (.06)	x	x	x	x	x	x	x	x	x	x
Read in input										

XII. CONCLUSIONS

This section deals solely with Phase II of the contract, the development of a benefit-cost model for wet-pavement accident reduction. As such, the conclusions concern the most important aspects of the model developed, rather than results of using the model, which is beyond the scope of the contract.

1. An extremely broad and flexible benefit-cost model was devised, and specifications were provided to FHWA for program implementation.

2. The model, although originally envisioned for application in evaluating countermeasures to wet-pavement accidents, is sufficiently complete in logic and data to be applied to a far broader range of accident types.

3. The project developed an exceedingly comprehensive tabulation of countermeasures that have been applied or proposed as wet-pavement accident reduction techniques, and the model provides distinct logic and analysis techniques for the two classes of countermeasures--those that modify the skid number and those that do not.

4. The model incorporates implicitly and explicitly the relationships between accidents and skid number developed in this project, and it is unlikely that states would be able to assemble data sufficient to supercede these relationships, other than possibly to better definitize them for <u>urban</u> highways.

5. Because the literature indicates that skid numbers and the changes of skid number with traffic and time are strongly dependent on local materials and practices, the model and support system permit users to supply values applicable to their area.

6. The data collected in the project define relations between accidents and skid number for highway sections, but not for spot locations. the model therefore treats spots as short, relatively high accident-rate locations with large skid number sensitivity.

7. The model incorporates the best estimates of effectiveness currently available for geometric and traffic control countermeasures, although it is expected that many of these estimates are overly optimistic and perhaps should be revised if the user has what he believes to be more realistic estimates.

8. The model incorporates a unique and comprehensive treatment of user delay and fuel consumption costs associated with construction zones that should have broad applicability outside the confines of this study.

9. The model is organized in anticipation that individual states will supply, via the support system data files, their own representative or average local values for expected lives, costs, and other characteristics of countermeasures, but it also anticipates that they may wish to use special or modified characteristics on occasions.

10. The project included a thorough review and critical assembly of the driver behavior literature and its application to potential behavior modification countermeasures (especially speed control) to the wet-pavement accident problem.

XIII. RECOMMENDATIONS

In a task of this sort, limited to the development of a tool, there are typically two types of recommendations--that the tool should be used, and that it can be improved. The development of the benefit-cost model for analyzing accident reduction countermeasures, is no different. Specifically, it is recommended that:

1. The benefit-cost model be implemented and applied by several states or regions of states, initially as a means of gaining national experience and confidence in its capabilities, and subsequently as a standard tool for providing highway administrators with benefit-cost data and comparisons for use in their decisionmaking.

2. The benefit-cost model be applied more universally than to just the special class of accidents that occur in association with wet pavement.

3. Additional test cases need to be devised to more thoroughly test some logical branches of the program.

4. Further data collection and analysis be conducted to better determine the role of skid number in accidents on urban facilities, but that until such determination, the relationships derived from the predominately rural data be utilized.

5. Additional analyses, and perhaps data, be acquired relative to the role of skid number on accident rates at spot locations.

6. The work reported relative to user costs associated with construction zones be expanded and applied as an element in overall construction and maintenance activity planning.

7. The scope of the model be expanded by adding the capability to evaluate combinations of feasible countermeasures for simultaneous implementation.

8. The scope of the model be expanded by adding the capability to evaluate countermeasures that change the highway type, such as from two-lane to multilane.

9. The model be expanded to incorporate a test of whether any known countermeasure could produce significant accident cost savings at a given site.

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APPENDIX A

POTENTIAL SKIDDING-ACCIDENT COUNTERMEASURES

The skidding-accident problem is a long-standing one and a multitude of countermeasures have been attempted to alleviate the problem. The skidding-accident problem can be reduced by reducing the frictional demand, by increasing the friction supply of the pavement, or by reducing the accident severity. Frictional demand can be reduced by either modifying the roadway geometry or by modifying driver behavior. An increase in frictional supply can be achieved by improved pavement design and improved tire design. Reduction of accident severity can be accomplished by constraining errant vehicles and by reducing obstacle hazards.

A list of potential countermeasures was developed and submitted to the 16 cooperating state transportation and highway departments* for review and comments. Below is the list of possible countermeasures for reducing the skidding-accident rates. The comments and suggestions resulting from the states' review are incorporated in the list. The countermeasures are classified under the three major headings mentioned above. Tire design is outside the scope of the study and is omitted from the listing.

Factors influencing driver behavior are extensive and involved. A complete description of the methods usable to influence driver behavior in controlling skidding is given in Appendix G.

I. Reducing Frictional Demand

A. Modifying Roadway Geometry

1. Curves

    a. Reduced curvature

    b. Reduce vertical curvature

    c. Increase superelevation

    d. Increase sight distance

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* The cooperating states contacted were: California, Connecticut, Florida, Louisiana, Maine, Maryland, Massachusetts, Michigan, Mississippi, North Carolina, Ohio, Pennsylvania, Rhode Island, South Carolina, Washington, and West Virginia.

    e. Install transition curves
    f. Remove ramp terminals and intersections on curves
    g. Eliminate broken back alignment
    h. Eliminate combinations of vertical and horizontal curves
    i. Increase cross slope on shoulders
    j. Stabilize and pave shoulders
    k. Widen shoulders
    l. Widen traveled way
    m. Relocate fixed objects

2. Tangents
    a. Reduce grades
    b. Increase sight distance
    c. Increase access control
    d. Lengthen weaving sections
    e. Stabilize and pave shoulders
    f. Widen shoulder
    g. Increase cross slope
    h. Widen traveled way
    i. Relocate fixed objects
    j. Add climbing lane
    k. Close median openings
    l. Add raised median

3. Intersections
    a. Increase sight distance
    b. Reduce grades on approach
    c. Install left turn lanes on through highway
        (1) Using raised/curbed island
        (2) Using painted island
    d. Lengthen/install acceleration/deceleration lanes
    e. Eliminate at grade intersections
    f. Improve intersection alignment
    g. Eliminate surface water "ponding" areas

B. <u>Modifying Driver Behavior</u>

1. Wet weather speed limits
2. Install safety lighting
3. Install slippery when wet signing
4. Install safe speed signing
5. Install advance signing
    a. Caution
    b. Directional (including informational or motorists service)
6. Install advance warning flashers
7. Eliminate concentrated message areas
8. Install overhead lane signs
9. Delineation

    - a. Install striping
        - (1) Edge and lane marking
        - (2) Double-yellow median line
        - (3) Painted median
        - (4) Centerline striping at crests
    - b. Install delineators
    - c. Install markers
        - (1) Reflectorized raised pavement markers
        - (2) Reflectorized guide markers
        - (3) Pavement rumble strips

10. Install glare barriers
11. Install intersection traffic control
    - a. Stop signs
    - b. Yield signs
    - c. Flashing beacons
    - d. Signals
        - (1) For vehicles phase
        - (2) For pedestrian phase
    - e. Timing of signals
    - f. Turn prohibitions
    - g. Turn control

12. Improve driver licensing
    a. Driver education
        (1) Driver education in high schools
        (2) Adult driver education
        (3) Driver education of problem drivers
        (4) Wet-weather driver training
    b. Law enforcement
        (1) Selective enforcement
        (2) Increase number of highway patrolmen on the road
        (3) Vehicle inspection (annual and spot)
    c. Physical exams of drivers
        (1) Vision
        (2) Hearing
        (3) Reaction time

II. <u>Increasing Frictional Supply</u>

A. <u>Selection of Aggregates</u>

1. Mineral hardness
2. Acid-insolubility test
3. Size
4. Gradation
5. Angularity

B. <u>New PCC Pavement Finish</u>

1. Burlap drag
    a. Oscillating
    b. Not oscillating
2. Brooming
3. Metal tines
4. Roller with ridges
5. Seeding with aggregate
6. Coco matting
7. Heavy belt
    a. Oscillating
    b. Not oscillating
8. Wallpaper brush
9. Wood float
10. Wire drag

C. <u>New Bituminous Concrete Pavement</u>

1. Prevent glazing by too-early traffic
2. Void content - prevent bleeding

D. <u>Maintenance</u>

1. Surface texturing
    a. Grooving
        (1) Longitudinal
        (2) Transverse

        - b. Etching
            - (1) Muriatic acid
            - (2) Hydrofluoric acid
            - (3) Hydrochloric acid
        - c. Abrading
            - (1) Christensen concrete planer
            - (2) Heater-planer
            - (3) Weighted section of chain-link fence
            - (4) Drum (with automatic punches for fracturing polished aggregate)
            - (5) Shot and sandblasting
        - d. Studs (on steel grid bridge decks)
    - 2. Overlays
        - a. Plant mix seal (open graded)
        - b. Bituminous chip-seal coat
        - c. Rubberized sand asphalt mixture
        - d. Synthetic resin mix
        - e. Mastic asphalt concrete
        - f. Epoxy resin seal coat
        - g. Epoxy resin mortar

III. <u>Reducing Accident Severity</u>

- A. Constrain errant vehicles
    - 1. Guardrails

2. Median Bariers

3. Favorable side slopes

B. <u>Reduce Obstacle Hazards</u>

1. Eliminate obstacles

2. Reduce obstacle severity

    a. Breakaway structures

    b. Guardrail diversion

    c. Impact attenuators

APPENDIX B

SKID RESISTANCE CHANGE WITH TRAFFIC PASSAGES IN THE BENEFIT-COST MODEL

The change in skid resistance during the life of a surface course can be important and needs to be incorporated in the benefit-cost model. With the current state of knowledge it appears necessary to forecast future skid numbers on the basis of local experience with specific aggregates in the climate of previous applications.

The need to employ local experience rather than national research results is due to the complexities of both the tire-pavement interactions and the mineraology of aggregates employed. This appendix presents a brief overview of the tire-pavement interaction, the surface wear and polish processes, and the over generalizations that appeared in early publications. The appendix concludes by presenting the analytical form employed in the benefit-cost model to characterize the changes in skid number due to traffic.

A more complete discussion of skid resistance is found in NCHRP Synthesis No. 14.

Knowledge on how the skid resistance of surface courses changes during the useful life of the pavement is an important feature required by the benefit-cost model. This appendix discusses briefly the fundamentals associated with the skid resistance of the tire-pavement interface. This is followed by a discussion of the mechanisms involved in the skid resistance changes experienced during the useful lives of asphaltic concrete and portland cement concrete surface courses. Finally, a description is given of the analytical form used by the benefit-cost model to characterize the change of skid number in terms of total cumulative vehicle passages.

1. Fundamentals of the Skid Resistance of the Tire-Pavement Interface: The braking and sidewise forces exerted on the tire by a pavement surface are thought to arise from three fundamental interactions. They are adhesion, hysteresis, and tearing or plowing.[39,41]

The tire actually contacts the surface only at a few asperities. On a wet pavement the tire must squeeze out a local film of water in the vicinity of the asperity to make contact. The tire adheres to the asperity surface and a force is required to produce relative motion.

When the tire moves with respect to the asperity the force required to deform the tire is not all recovered as the deformed area moves from the asperity. Consequently, to cause displacement a net force is required to overcome the hysteresis losses. Similar hysteresis contributions to braking and side forces arise from deforming the tire over larger features of the pavement surface, even though most of the areas involved may be separated by water or other attached films.

Microscopic examinations have been made of tire surfaces after slipping against pavement surfaces in laboratory tests. The examinations reveal that the tire is gouged or torn by microscopic asperities when they are high and sharp. The forces required to cause the permanent deformations also contribute to braking and sidewise forces exerted on the tire by the pavement.

The microscopic asperities, their frequency, dimensions, and character are called the microtexture. The larger scaled variation in surface height, generally associated with small and large aggregate, is called the macrotexture. The macrotexture is in the true sense associated with the pavement surface. Microtexture is used to describe a pavement characteristic but is more correctly associated with individual pieces of aggregate.

The macrotexture of the pavement surface is also important in providing escape channels for water under the tire footprint. When vehicle speed is increased there is a reduction in the time available for water to be forced from under the tire, and the water pressure then increases. If the passages formed by the macrotexture do not supply sufficient egress, water pressure will rise sufficiently to support the tire, and contact with the pavement will be reduced or eliminated. The extreme condition of no contact is called hydroplaning; negligible braking and sidewise forces can be transmitted in this condition. It is important to recognize that hydrodynamics can provide partial tire support which reduces the maximum magnitudes of braking and sidewise forces otherwise attainable.

Consider again the three fundamental processes which provide braking and sidewise forces on the tire. The adhesion process does not require any relative motion between tire and pavement. The force contribution from hysteresis and gouging do require relative motion. The maximum braking force on a wet pavement is usually attained when the tire motion is a combination of rolling and slipping. The peak skid number is obtained under these conditions and is equal to the indicated friction coefficient times 100. The skid number generally in use is smaller and is obtained experimentally with a locked wheel; it is the coefficient of friction for that condition times 100. Most state highway departments employ locked-wheel test trailers and obtain data as skid numbers. A few states, and other countries, measure forces on a yawed tire (the Mu-meter), which provides a result which is frequently larger than the skid number but is not necessarily the peak skid number.

2. Asphaltic Concrete Surface Courses: As the name implies, asphaltic concrete (AC) is a coalescence of mineral aggregate bound together by asphalt or mixtures of asphalt and other binder extenders. A large body of knowledge has been developed by investigators on the characteristics of AC and on emplacement practices.[20,21,47,51,53,58] A characteristic

of special interest here is the skid number provided during the life of the surface course. However, the cost, useful life, and structural properties are also important characteristics. After examining the literature it appears that frequently generalizations have been deduced or suggested about the variation of skid number over the life of the pavement without regard for the complexities of the subject and without appreciation for the lack of scope in individual investigations. Unfortunately, there are few legitimate generalizations that can be broadly applied for the purpose of this project. This can be seen from the following description of the life of an asphaltic surface course, which was developed from pertinent findings of several investigators.

When AC is mixed, prior to emplacement, the aggregate are coated with asphalt, which is rendered workable by one of three techniques. The asphalt may be heated (together with the aggregate), reduced (or cut) with volatile petroleum components, or processed as a water emulsion. The quality and durability of the emplaced course depend on the ambient temperature, the surface temperature and preparation, the temperature or condition of the mix, the rolling schedule, and the post-emplacement protection from traffic.

The grading of aggregates used can produce courses with a very small percentage of voids (close-graded), or with a large percentage of voids (open-graded). With the same type of aggregates and asphalt the close-graded course has higher structural strength and is less subject to deformation or freeze damage. The open-graded course provides more drainage passages for water, and, in very high void designs, may actually provide a subsurface path for gross drainage to the pavement edges.

When traffic first uses the surface, tires contact the asphalt coating which usually contains fines and possibly some small aggregate. For this initial wear-in period there are very little skid data and the skid number results are described variously as low or satisfactory. These results probably depend on the character of the fine and small aggregate and the initial macrotexture resulting from gradation and rolling.

As wear due to traffic continues the asphalt is worn off the large aggregate and in many pavements the majority of actual contact occurs between the tires and large aggregate.

The aggregate (of any size) that is contacted by tires is subject to wear and polish. Wear is the removal of surface material, and polish is the preferential removal of asperities so that their number and protuberance are diminshed. The wear and polish together with initial grading and asphaltic degradation determine the skid resistance in the early and subsequent life of the surface.

The exposed aggregate may previously have been polished by natural processes as in the case of river or glacial gravels. In this case the early skid numbers may be low and change little with time and traffic. If, however, the aggregates have been crushed or naturally have numerous asperities, the early skid numbers may be high. The subsequent changes in skid number depend on several interacting factors. These factors and the ensuing progression of skid numbers are areas in which unwarranted generalizations have been advanced.

From a practical standpoint there are two kinds of aggregate: those that wear and polish, and those that wear without becoming polished. However, there has been some confusion about these classes.

Aggregate that wears and polishes may differ significantly in the rate at which polishing progresses. Generally, the soft minerals polish rapidly while the hard minerals polish slowly. The differences in polishing rates were first observed with practical consequences. The rapid polishing aggregate quickly became slick (contributing to low skid numbers), while in comparable time periods and traffic, the slow-polishing aggregates retained most of their initial skid number. As a result of these observations there was a tendency to describe the slow-polishing aggregate as nonpolishing and the rapidly polishing aggregate as polishing or polish prone. There is, of course, a great practical difference between the rapid- and slow-polishing aggregate. In the case of the life history of a surface course, the rapid-polishing aggregates would, after a small number of traffic passages, deteriorate to a low skid number, while the slow-polishing aggregates might in the same service provide much higher skid numbers for time periods comensurate with the expected life of the surface course. Ultimately, investigators recognized that it is simply a matter of time and traffic differences: slow-polishing aggregate will finally polish and provide low skid numbers. This similarity may have been overemphasized in some cases where it could be inferred incorrectly that all aggregates polish.

Nonpolishing aggregates can be subdivided into two types. In one type the mineral characteristics are essentially uniform and the nonpolishing characteristic arises from the crystallography. Wear occurs with the removal of geometric elements that expose new micro surfaces with angularity and asperities. The aggregates that are manufactured by kilning shales and clays are of this type. The second type has nonhomogeneous mineral characteristics. Typically the rock will be a (naturally) cemented gritstone or sandstone. The angularity of the embedded sand or grit supplies the asperities. The individual embedded particles may polish but they have a limited life at the exposed surface because cementation fails due to wear or weathering. Consequently, new embedded particles are exposed and provide a renewal of unpolished surface.

The character of wear in the nonpolishing aggregate suggests that material may be removed in larger increments than for polishing aggregate. Some test data also indicate rather high wear rates. Consequently, the skid number should remain high with nonpolishing aggregate as long as they provide the major peaks in the macrotexture. However, there may be a long-term problem with wear and rutting.

There are natural mineral aggregates with characteristics that suggest a range of polish susceptibility. Some soft mineral formations have inclusions of harder materials. It has been suggested that these aggregate have a minimum skid number that is superior to the skid number of aggregate composed of completely homogeneous minerals. Laboratory tests have shown that there is correlation (negative) between minimum coefficients and insoluable content. However, the correlation is not strong enough to make the test for insoluables a useable predictor for skid number. When a further classification is made as to shape and size of the insoluables their presence is strongly correlated with minimum skid number.

The particulate debris formed by wear (detritus) have an effect on the rate of wear and polishing. Laboratory tests of slipping tires on pavement samples show that polish progresses at a faster rate when detritus are left in the wheel path. However, the minimum friction coefficient achieved with detritus present is larger than the coefficient that is reached when the pavement is flushed. The detritus in the tire-pavement interface remove asperities at a faster rate than does the clean tire. However, the detritus must generate some low order asperities in the process so that a higher polish can be achieved when the detritus are removed.

The relative abundance and absence of detritus have been considered as one explanation for skid number variations that appear to be seasonal. The explanation is applicable if the exposed aggregate have been polished with detritus present close to the minimum achievable skid number. This would occur at the end of the "dry season". During the wet season additional polishing would occur when the detritus are repeatedly flushed from the road. At the end of the wet season a minimum skid number would be reached. And, during the ensuing dry season the detritus, left on the road, would produce wear and create a low level microtexture so that skid number should increase again.

Field data have not been obtained with sufficient precision and in sufficient quantities to explain the detritus-season effects. It should be recognized that this seasonal effect would not be the same nationwide, because the patterns of precipitation differ from region to region. Factors in skid number measurement are also suspected of reflecting seasonal effects.

The skid numbers of asphaltic concrete surfaces are also influenced by other changes caused by time and traffic. The exposed surfaces of the asphalt are subject to chemical and physical change due to solar radiation, oxidation, and attack by contaminants in the atmosphere and surface water. As a result the asphalt is slowly lost from exposed surfaces. This may expose new fines and small aggregate that constitute part of the pavement surface in direct contact with the tire. The newly exposed aggregate have not been polished and may constitute a continually renewed source of effective asperities.

The atmospheric and surface water contaminants may also attack aggregate surfaces. No data were found on this subject but it appears likely that the chemical attack will be nonuniform due to small variations in the composition or crystallography within the individual pieces of aggregate. Thus, it is likely that in the absence of wear and polishing, some level of microtexture would be formed on exposed aggregate surfaces.

The environmental attacks on the asphalt and on exposed aggregate surfaces appear to renew or form microtexture. It is important to recognize that these processes are in competition with polishing due to traffic.

The skid resistance provided by an asphaltic concrete surface course during its useful life is seen to depend on numerous variables. They include: the asphalt characteristics, the mineral and crystallography of the aggregate, the initial state of the aggregate, the size grading of aggregate, the total vehicle passages and the traffic flow rates, the seasonal rainfall patterns, and possibly the atmospheric and surface water contaminants.

For surface courses with polishing aggregate the usual history of skid numbers includes a relatively large initial value that depends on the initial condition of the aggregate. The skid number diminishes with vehicle passages. Some investigators find that the skid number stabilizes to a nearly constant value after a large number of vehicle passages. Other investigators find that the nearly constant final skid number has an inverse relation to the traffic flow rate. When the polishing and renewal processes are considered together with the variety of aggregates it seems likely that both findings may be correct. Consider first the case where a final, nearly constant skid number appears insensitive to traffic flow rates. The microtexture renewal processes in this case are simply too weak and slow to compete with any of the polishing processes caused by the range of traffic flows investigated. In contrast, the sensitivity to traffic flow rate indicates that microrenewal and polishing processes are in effective competition for the range of variables involved.

For surface courses with truly nonpolishing aggregate the history of skid resistance is very different from the cases with polishing aggregates. If all the large aggregate are nonpolishing it is likely that the skid number will increase with traffic usage. Some pavements exhibit skid number increases over long periods of time. Presumably the long-term increases are associated with wear that brings more of the nonpolishing surfaces into contact with tires.

Since both the natural and manufactured nonpolishing aggregates are expensive, attention has been directed to mixtures of polishing and nonpolishing aggregates. Findings are not entirely consistent; however, it appears that for substantial benefits it is necessary to use the nonpolishing variety for 50% or more of the large aggregate. In these investigations it appears that insufficient attention has been paid to the relative wear rates of the polishing and nonpolishing aggregates used in combination. The relatively high wear rates of the nonpolishing aggregates may diminish their contacts with tires when mixtures of polishing and nonpolishing aggregates are used.

The skid resistance exhibited by an asphaltic concrete surface during its useful life is the result of several variables in complex interactions. The complexity has an impact on this study. Namely, it is not realistic to predict for nationwide application the skid resistance exhibited by asphaltic concrete pavements during their useful lives. It is realistic to provide analytical forms with coefficients that can be assigned by individual state highway departments. The assignments can be based on the state experiences with their aggregates, emplacement practices, and climatic conditions. It will also be possible to supply coefficient values that will provide approximations when only the general character of the aggregate is known.

Some seal and chip coats exhibit skid resistance characteristics similar to those of the asphaltic concrete. The polishing and nonpolishing characteristics of the chips have influences similar to those of the aggregate. The chip size and emplacement procedure sets initial macrotexture. Macrotexture diminishes with traffic due to wear and to the dislodgement of aggregate.

A very undesirable situation arises when a large part of the chips are lost by wear or dislodgement. The tire then contacts the seal material, which has poor macrotexture and most likely poor microtexture.

Sand slurries are now used only infrequently. They have poor macrotexture but may have good microtexture associated with the sand particles. Also, the microtexture may be renewed through the loss of exposed sand and the recession of the binder.

3. Portland Cement Concrete Surface Courses: PCC surface courses also exhibit skid resistance changes during their useful lives. These changes are discussed in terms of three pavement surface periods. In the first period, the initial texture (macrotexture) of the PCC surface is that formed in the plastic concrete, conventionally by brooming or burlap drags. The texture is formed in mortar that is composed of the cement with fine and some small aggregate. Early wear removes the cement from some of the fine and small aggregate. This, in combination with areas of cement, supply the microtexture. The skid numbers in early life of PCC depend on the adequacy of the formed macrotexture and the microtextures of the fine and small aggregate. These aggregate may be subject to polishing, so that the skid number will be influenced by the relative rates of wear and polishing. Wear removes exposed aggregate and exposes previously unpolished particles. It is paradoxical that during this first period a poor cement (fast wearing) will tend to hold the skid number near to that maximum associated with the unpolished fine and small aggregate. This first period ends when wear reduces the macrotexture to a hazardously small value.

The formed macrotexture may wear off before any larger aggregates are exposed. In the second period, a small macrotexture due to the small aggregates may persist for some time. The standard skid number measured at 40 mph may not be alarmingly low during this period but heavy rainfalls, poor drainage, and high vehicle speeds may combine to produce high skid potentials from partial hydroplaning.

A third period for the PCC surface begins when larger aggregate are exposed and create a larger macrotexture. The texture formed must depend on the relative wear rates of the large aggregate and the mortar. The polishing characteristics of large aggregate should have a pronounced effect on skid number during this third period.

The skid resistance of PCC surfaces during their useful lives are influenced by a number of interacting variables. Again, it is not realistic to provide predictions of PCC skid numbers that will be useful nationwide. In the case of PCC it is even difficult to choose analytical forms that may have general utility.

The conventional macrotexture formed by brooms or drags has in some cases been replaced by grooving. Grooves can be cut or ground into the cured pavement, or can be formed while the concrete is in the plastic state. Judging from the literature[7,13,63] it appears that most post-plastic state grooving has been performed on pavements in the second period (small macrotexture) in the attempt to reduce high wet-pavement accident rates. This remedial treatment appears to have been very effective, even though standard skid measurements do not indicate large increases in skid number.

For almost all the groove geometrics used, an effective macrotexture is assured. However, the grooved pavement wears more rapidly than the same surface ungrooved. Initially the edges wear so that larger aggregate may be exposed there sooner than in an ungrooved pavement. When grooves are formed in the plastic state the presence of the groove macrotexture and the subsequent uneven wear should prevent the surface from attaining a second period character with small, ineffective macrotexture. The increased wear rates may also provide improved microtexture due to accelerated renewal and exposure.

Some of the pavements that were first grooved (in a cured state) are now worn and the grooves in the wheel tracks virtually eliminated. It remains to be seen if the wear processes on the surface will perpetuate a satisfactory macrotexture.

There is a safety aspect of grooving that has not been considered by investigators. Most grooves are visible or can be sensed from vehicle responses. As a result grooves may alert drivers and provide a safety benefit that is not associated with wet-pavement skid resistance. This concept is reinforced by the fact that a reduction in dry-pavement accident rates has followed grooving at some sites.

4. Form of Skid Number Variations with Vehicle Passages: A review of the literature and a subsequent analysis indicated that a logarithmic form may be suitable to characterize the change of skid number with vehicle passages. Following the work of Rizenbergs et al,[57] the form is

$$SN = SN_o + C_s \ln (C_t \times 10^{-5})$$

where

SN = skid number,
SN_o = initial skid number after a wear-in period,
C_s = pavement coefficient, and
C_t = total (accumulated) vehicle passages since the pavement surface was opened to traffic.

This form does not account for the initial wear-in of asphaltic concrete, a period when the asphalt, the fines, and some small aggregate are worn off to expose the large aggregate. Outside of this limitation, the form has been shown[57] to be useful to describe the skid number of both standard asphaltic and portland cement concrete surface courses. The form with C_s positive may also be suitable for asphaltic courses made with manufactured aggregate. The general character of the curves for these nonpolishing surfaces indicates that the equation should be suitable; however, no numerical tests have been made.

The above form relating skid number changes with vehicle passages is incorporated in the benefit-cost model along with the following limits:

1) $C_t \times 10^{-5}$ is replaced by 1.0 when $C_t \times 10^{-5}$ is ≤ 1.0,

2) If $C_s > 0$, then SN has a maximum of SN_f (final SN for surface), and

3) If $C_s < 0$, then SN has a minimum of SN_f

All coefficients and limit values appear in the benefit-cost program as subscripted values applicable to a specific surface course. Specific values of the coefficients must be assigned by the individual state highway departments using the model. The values of C_s are best determined from least-square curve fits of state-collected pavement data.

APPENDIX C

ACCIDENT COSTS

Accident costs are changing rapidly. The costs of accidents are determined in the model from cost data published by the National Highway Traffic Safety Administration (NHTSA) and from several factors described below including the distribution of accident severities. While the distribution of accident severities is expected to be more stable over time than are accident costs, it is intended that both the accident cost and severity distributions used in the model should be updated at intervals commensurate with their rates of change.

The following accident costs are incorporated in the model:

Symbol	Definition	Cost
CT1	Cost per vehicle involved in a property-damage-only accident	$ 300
CT2	Cost per injury	7,300
CT3	Cost per fatality	200,700

These costs were obtained from "Societal Cost of Motor Vehicle Accidents, Preliminary Report," published by NHTSA in April 1972. The NHTSA cost for a fatality is higher than other available estimates, such as those published by the National Safety Council, primarily because the NHTSA costs include the value of future earnings lost due to an accident. The use of the NHTSA costs in benefit-cost evaluations by state and local governments has been recommended by the U.S. Department of Transportation in the Highway Safety Program Manual,[37] and is therefore most appropriate fcr use in this model.

It is recognized that users of the model may wish to modify the accident costs employed in a particular analysis. Therefore, the user may specify weight factors that modify the costs, as optional input to the model. These weight factors are identified below as FPD, FIA and FFA for property-damage-only, injury and fatal accidents, respectively, and have default values of 1.0.

The average cost of a property-damage-only accident is:

$$CA1 = (CT1)(FPD)(AP1)$$

where CA1 = Average cost of a property-damage-only accident

CT1 = Average cost per involved vehicle in property-damage-only accidents

FPD = Weight factor for property damage costs (default value = 1.0)

AP1 = Average number of vehicles involved in a property-damage-only accident

In the same manner, the cost of an injury accident is:

CA2 = (CT2)(FIA)(AP2)

and the cost of a fatal accident is:

CA3 = (CT3)(FFA)(AP3)

where CA2 = Average cost of an injury accident

CT2 = Average cost of an injury

FIA = Weight factor for injury costs (default value = 1.0)

AP2 = Average number of injured persons per injury accident

CA3 = Average cost of a fatal accident

CT3 = Average cost of a fatality

FFA = Weight factor for fatality costs (default value = 1.0)

AP3 = Average number of fatalities per fatal accident.

In the analysis of each countermeasure, the model determines a weighted-average cost per accident for the accidents remaining after the countermeasure is implemented. This overall average cost is defined as:

CAA = (CA1)(FA1) + (CA2)(FA2) + (CA3)(FA3)

where CAA = Weighted-average cost of all accidents

FA1 = Fraction of all accidents that involve property-damage-only

FA2 = Fraction of all accidents that involve injuries

FA3 = Fraction of all accidents that involve fatalities

Table 15 shows how AP2, AP3, FA1, FA2 and FA3 depend on area type and highway type. This table was assembled using data supplied by the States of California, Michigan and Washington for their entire state highway systems. The California and Washington data used are for the years 1972 through 1975 and the Michigan data are for the years 1971 through 1974.

The number of vehicles involved per property-damage-only accident (AP1) was reported as 1.71. No breakdown of AP1 by area type and highway type is available.

Table 16 illustrates the coefficients actually used in accident cost equations in the model. The table illustrates both the numerical value and the computer symbol used for each coefficient.

TABLE 15

DISTRIBUTION OF ACCIDENT SEVERITIES

Area Type	Highway Type	Fatal Accidents*	Fatally Injured Persons*	Fatally Injured Persons Per Fatal Accident (AP3)	Injury Accidents*	Injured Persons*	Injured Persons Per Injury Accident (AP2)	Property-Damage-Only Accidents*	Total Accidents*	Percent Fatal Accidents (100FA3)	Percent Injury Accidents (100FA2)	Percent Property-Damage-Only Accidents (100FA1)
Rural	Two-Lane	3,828	4,664	1.22	67,184	111,442	1.66	121,365	192,377	1.99	34.92	63.09
Rural	Multilane Uncontrolled Access	959	1,168	1.18	23,260	39,042	1.68	43,924	68,143	1.41	34.13	64.46
Rural	Multilane Controlled Access	1,475	1,787	1.21	24,091	39,154	1.63	46,480	72,046	2.05	33.44	64.51
Urban	Two-Lane	430	486	1.13	21,308	32,287	1.52	47,191	68,929	0.63	30.91	68.46
Urban	Multilane Uncontrolled Access	1,608	1,783	1.11	106,248	159,709	1.50	227,435	335,291	0.48	31.69	67.83
Urban	Multilane Controlled Access	2,128	2,382	1.12	73,522	108,965	1.48	165,225	240,875	0.88	30.52	68.60

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* Data in the columns with astericks were obtained directly from the States of California, Michigan and Washington, and apply to the entire state highway system in those states. The California and Washington data are for the years 1972-1975 and the Michigan data are for the years 1971-1974.

TABLE 16

COEFFICIENTS FOR ACCIDENT COST EQUATIONS

Area Type (JA)	Highway Type (JH)	Average Number Per Accident and Computer Symbol			Fraction of Accidents by Severity and Computer Symbol		
		Vehicles/ Property-Damage-Only Accident	Injured Persons/ Injury Accident	Fatalities/ Fatal Accident	Property-Damage-Only	Injury	Fatal
Rural (JA = 1)	Two-Lane (JH = 1)	1.71 AP1(1)	1.66 AP2(1)	1.20 AP3(1)	0.6309 FA1(1,1)	0.3492 FA2(1,1)	0.0199 FA3(1,1)
Rural (JA = 1)	Multilane Uncontrolled Access (JH = 2)	1.71 AP1(1)	1.66 AP2(1)	1.20 AP3(1)	0.6446 FA1(1,2)	0.3413 FA2(1,2)	0.0141 FA3(1,2)
Rural (JA = 1)	Multilane Controlled Access (JH = 3)	1.71 AP1(1)	1.66 AP2(1)	1.20 AP3(1)	0.6451 FA1(1,3)	0.3344 FA2(1,3)	0.0205 FA3(1,3)
Urban (JA = 2)	Two-Lane (JH = 1)	1.71 AP1(2)	1.50 AP2(2)	1.12 AP3(2)	0.6846 FA1(2,1)	0.3091 FA2(2,1)	0.0063 FA3(2,1)
Urban (JA = 2)	Multilane Uncontrolled Access (JH = 2)	1.71 AP1(2)	1.50 AP2(2)	1.12 AP3(2)	0.6783 FA1(2,2)	0.3169 FA2(2,2)	0.0048 FA3(2,2)
Urban (JA = 2)	Multilane Controlled Access (JH = 3)	1.71 AP1(2)	1.50 AP2(2)	1.12 AP3(2)	0.6860 FA1(2,3)	0.3052 FA2(2,3)	0.0088 FA3(2,3)

APPENDIX D

ADDITIONAL USER COSTS DUE TO CONSTRUCTION

This Appendix discusses the development of user costs associated with construction and maintenance activities associated with countermeasure implementation. The user cost factors that are given directly are travel time delay in vehicle-hours of delay per day and excess fuel consumed in gallons of fuel per day. Costs are determined from these factors by specifying the unit value of vehicle delays and the costs of fuel.

This Appendix first summarizes the various formulas and values used for the determination of delays and fuel consumption, and then presents the reasoning, assumptions and data used in developing the formulas.

1. Summary: Five typical construction zone configurations are specified, based on the roadway type before construction and the number of lanes open during construction. The zone configurations considered are as follows:

1. Two-way, two-lane roadway reduced to one lane with alternating directions of traffic.

2. Two unidirectional lanes reduced to one lane.

3. Two-way, four-lane, divided highway reduced to two-way, two-lane.

4. Three unidirectional lanes reduced to two lanes.

5. Three unidirectional lanes reduced to one lane.

Formulas for vehicle-hours of delay and excess fuel consumed were developed from curve fits for configurations 1 and 2 only. Data are presented that could be used to develop formulas for the delay and fuel consumed for the other three configurations.

Five area type-closure schedule combinations are considered for each zone configuration. These are shown in Table 17. The information necessary to develop formulas for other scheduling alternatives can be found in the following sections.

a. Two-lane, two-way highway reduced to one lane (Configuration 1): On a two-lane, two-way highway reduced to one lane with alternating directions of traffic the formulas for delay and excess fuel consumed are as follows:

Vehicle Hours of Delay

$$D = [(C_1A + C_2A^2 + C_3A^3)/(d_o + d_1A)]\ell$$

where D = Vehicle-hours of delay per day,

A = ADT/1,000 (both directions summed), and

ℓ = Length of one-lane section (miles).

Table 18 provides the coefficient values.

TABLE 17

AREA TYPE - CLOSURE SCHEDULE COMBINATIONS

Code	Area Type	Lane Closure Schedule
U-1	Urban	Lanes closed 24 hr a day
U-2	Urban	Lanes closed at all times except 6 to 8 AM and 3 to 6 PM
U-3	Urban	Lanes closed 8 AM to 3 PM
R-1	Rural	Lanes closed 24 hr a day
R-2	Rural	Lanes closed 8 AM to 4 PM

TABLE 18

COEFFICIENTS FOR DELAY EQUATION (Configuration 1)

Area Closure Schedule Code	Schedule	C_1	C_2	C_3	d_o	d_1
U-1	All 24 hr	1055.23	-24.0705	-0.527063	23.0	-1.0
U-2	6 to 8 AM and 3 to 6 PM	30.708	0.007222	0.038444	1.0	0.0
U-3	8 AM to 3 PM	17.0173	-0.004555	0.026622	1.0	0.0
R-1	All 24 hr	1055.23	-24.0705	-0.527063	23.0	-1.0
R-2	8 AM to 4 PM	24.650	0.508656	0.074933	1.0	0.0

Excess Fuel Consumed

$$G = C_1A + C_2A^2 + C_3A^3 + C_ID$$

where G = Excess gallons of fuel consumed per day,

A = ADT/1,000 (both directions summed),

C_I = Average consumption at idle, gal/vehicle-hour, and

D = Vehicle-hours of delay per day.

Table 19 gives the coefficient values.

TABLE 19

COEFFICIENTS FOR EXCESS FUEL CONSUMPTION EQUATION (Configuration 1)

Area Closure Schedule				
Code	Closure	C_1	C_2	C_3
U-1	All 24 hr	22.35-8.5767ℓ a/	-0.325+0.48907ℓ a/	-0.007787ℓ a/
U-2	6 to 8 AM and 3 to 6 PM Excluded	14.15-4.8047ℓ	-0.165+0.16417ℓ	-0.000395ℓ
U-3	8 AM to 3 PM	7.70-2.9876ℓ	-0.100+0.15609ℓ	-0.002112ℓ
R-1	All 24 hr	22.35-8.5767ℓ	-0.325+0.4897ℓ	-0.007787ℓ
R-2	8 AM to 4 PM	7.70-2.9876ℓ	-0.100+0.15609ℓ	-0.002112ℓ

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a/ The multiplier, ℓ, is the length of the one-lane section (miles).

The average fuel consumption at idle, C_I, is 0.376 gal/vehicle-hour for the traffic composition including 10% trucks.

b. Two unidirectional lanes reduced to one unidirectional lane (Configuration 2): On a highway with two unidirectional lanes reduced to one unidirectional lane, the formulas for delay and excess fuel consumed are as follows:

Vehicle Hours of Delay

$$D = C_o + C_1A + C_2A^2 + C_3A^3$$

where

D = Vehicle-hours of delay per day

A = ADT/1,000 (ADT in the direction affected)

Table 20 presents the coefficient values.

Excess Fuel Consumed

$$G = C_o + C_1A + C_2A^2 + C_3A^3$$

where

G = Excess fuel consumed (gallons/day)

A = ADT/1,000 (ADT in direction affected)

Table 21 provides the coefficient values.

2. Development of delay formulas for two-way two-lane highway reduced to one-lane with alternating traffic (Configuration 1): In this configuration one direction of traffic is stopped while vehicles traveling in the opposite direction travel through the one-lane portion of the roadway. Figure 11 is a diagram of a typical work site of this configuration. Traffic control is normally accomplished by flagmen or signals at each of the stop lines.

The operation of this type of zone, of course, is cyclic. A cycle of length T hours consists of four elements:

$$T = t_{c1} + t_t + t_{c2} + t_t$$

where

t_{c1} = Time for released vehicles to clear stop line (hours), direction 1

t_{c2} = Time for released vehicles to clear stop line (hours), direction 2

t_t = Time for last of released vehicles to travel the one-way section (hours).

The types of delays that a vehicle may experience in this zone configuration are:

1. Stopped delays

2. Delays due to reduced speeds

TABLE 20

COEFFICIENTS FOR THE DELAY EQUATION (Configuration 2)

Area Closure Schedule Code	Closure	Range of A	Co	C1	C2	C3
U-1	All 24 hr	0 to 23	0	-0.39276ℓ [a]	0.23930ℓ [a]	0.003488ℓ [a]
		23 to 30[b]	39,675	$-3450.0-0.39276\ell$	$75.0+0.23930\ell$	0.003488ℓ
U-2	6 to 8 AM and 3 to 6 PM Excluded	0 to 35	0	0.147755ℓ	0.073776ℓ	0.002554ℓ
		35 to 38	28,175	$-1610.0+0.14775\ell$	$23.0+0.073776\ell$	0.002554ℓ
U-3	8 AM to 3 PM	0 to 35	0	0.13767ℓ	0.038042ℓ	0.001949ℓ
		35 to 38	52,307	$-2989+0.13767\ell$	$42.7+0.038042\ell$	0.001949ℓ
R-1	All 24 hr	0 to 23	0	-0.39276ℓ	0.23930ℓ	0.003488ℓ
		23 to 30[b]	39,675	$-3450.0-0.39276\ell$	$75.0+0.23930\ell$	0.003488ℓ
R-2	8 AM to 4 PM	0 to 35	0	0.13767ℓ	0.038042ℓ	0.001949ℓ
		35 to 38	52,307	$-2989+0.13767\ell$	$42.7+0.038042\ell$	0.001949ℓ

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[a] The multiplier, ℓ, is the length of the one-lane section plus 0.20 (miles).

[b] The 24-hr closure is very undesirable at A >30 because of long queues and long delays per vehicle.

TABLE 21

COEFFICIENTS FOR EXCESS FUEL CONSUMPTION EQUATION (Configuration 2)

Area Closure Schedule Code	Closure	Range of A	C_o	C_1	C_2	C_3
U-1	All 24 hr	0 to 23	0	$1.99482+1.18790\,\ell$ a/	$0.40671-0.78473\,\ell$ a/	$0.003178+0.014194\,\ell$ a/
		23 to 30 b/	$39675\ C_I$ c/	$1.99482+1.18790\,\ell\ -3450\ C_I$ c/	$0.40671-0.78473\,\ell\ +75.0\ C_I$ c/	$0.003178+0.014194\,\ell$
U-2	5 to 8 AM and 3 to 6 PM Excluded	0 to 35	0	$-0.032732+1.21555\,\ell$	$0.34387-0.45329\,\ell$	$-0.002561+0.006874\,\ell$
		35 to 38	$28175\ C_I$	$-0.032732+1.21555\,\ell-1610\ C_I$	$0.34387-0.45329\,\ell+23.0\ C_I$	$-0.002561+0.006874\,\ell$
U-3	8 AM to 3 PM	0 to 35	0	$0.24635+0.87530\,\ell$	$0.18055-0.29866\,\ell$	$-0.000919+0.004813\,\ell$
		35 to 38	$52307\ C_I$	$0.24635+0.87530\,\ell-2989\ C_I$	$0.18055-0.29866\,\ell+42.7\ C_I$	$-0.000919+0.004813\,\ell$
R-1	All 24 hr	0 to 23	0	$1.99482+1.18790\,\ell$	$0.40671-0.78473\,\ell$	$0.003178+0.014194\,\ell$
		23 to 30 b/	$39675\ C_I$	$1.99482+1.18790\,\ell-3450\ C_I$	$0.40671-0.78473\,\ell\ +75.0\ C_I$	$0.003178+0.014194\,\ell$
R-2	8 AM to 4 PM	0 to 35	0	$0.24635+0.87530\,\ell$	$0.18055-0.29866\,\ell$	$-0.000919+0.004813\,\ell$
		35 to 38	$52307\ C_I$	$0.24635+0.87530\,\ell-2989\ C_I$	$0.18055-0.29866\,\ell+42.7\ C_I$	$-0.000919+0.004813\,\ell$

---

a/ The multiplier, ℓ, is the construction zone length plus 0.2 (miles).

b/ The 24-hr closures (U-1 and R-1) are undesirable for ADT $>$ 30,000 because queues lengths and delays will be excessive.

c/ The multiplier, C_I, is the average fuel consumption at idle (gal/vehicle hr). C_I is 0.376 gal/vehicle-hr for the traffic composition including 10% trucks.

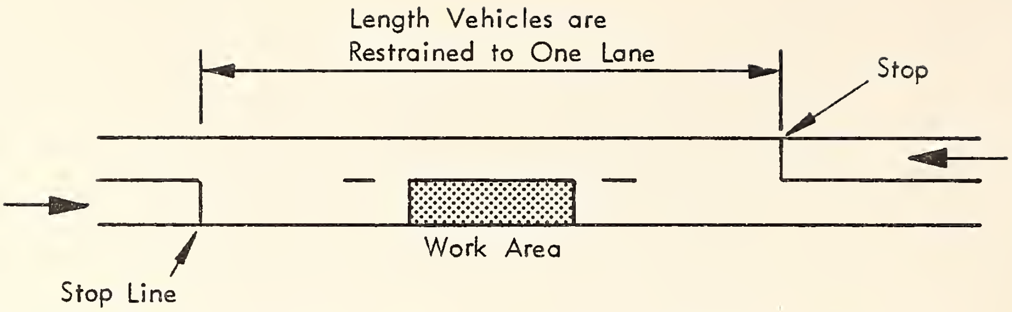


Figure 11 - Two-Way, Two-Lane Highway Reduced to One Lane (Configuration 1)

The computation of the delays is dependent on the mode of operation of the zone. The two modes of operation are saturated and unsaturated. The distinction between these two modes is addressed next.

In general, the numbers of vehicles served during one cycle at saturation conditions are:

$$n_1 = t_{c1}{*}R, \text{ and}$$

$$n_2 = t_{c2}{*}R$$

where

n_1 = Number of direction 1 vehicles served in one cycle

n_2 = Number of direction 2 vehicles served in one cycle

R = Approach flow rate (vph) at intersection capacity

The total number of vehicles served per cycle is:

$$n_1 + n_2 = R(t_{c1} + t_{c2}).$$

But $(t_{c1} + t_{c2}) = T - 2t_t.$

Therefore $n_1 + n_2 = R(T - 2t_t).$

And, since there are $\frac{1}{T}$ cycles per hour, the volume served (vph) during saturated conditions is:

$$V_1 + V_2 = R\ (1 - 2t_t/T) \text{ vehicles/hour}$$

Clearly, the volume served is maximized by taking long cycles (large T). However, an upper limit on acceptable cycle length for drivers is about 5 min or 1/12 hr. This value is taken as the condition separating two modes of operation. This should reduce delay under those conditions. For demand volumes, $V_1 + V_2$, above $R\ [1 - 2t_t/(1/12)]$, the facility is saturated or oversaturated, and the cycle time T, of 1/12 hr will result in queues that will grow at each of the two approaches. For demand volumes less than that value the cycle period will be set by the demand.

When the cycle period, T, is set by the demand, the period t_c is sufficient to exhaust the queue in each direction.

Thus,

$$t_{c1} = V_1 T/R, \text{ and}$$

$$t_{c2} = V_2 T/R.$$

This simply states that the time required for the i^{th} direction vehicles to clear the stop line is sufficient to clear all vehicles that arrive in one cycle. Then, since

$$T = t_{c1} + t_{c2} + 2t_t = (V_1 + V_2)\, T/(R) + 2t_t,$$

$$T = \frac{2t_t}{1 - \dfrac{V_1 + V_2}{R}} .$$

This equation gives the desired cycle period under unsaturated conditions.

a. Delays due to stopping: We first consider the unsaturated case. For direction 1 the stopped delays during a cycle start when the period t_{c1} ends. We count time from that origin in the following development. Vehicles arrive at the rate V_1 per hour and are stopped. The first vehicle to arrive and be stopped is released after time $(t_{c2} + 2\,t_t)$. The last vehicle stopped in direction 1 crosses the stop line at time $(t_{c2} + 2t_t) + (t_{c2} + 2t_t)\cdot V_1 R$, where the second term accounts for clearing time required for vehicles in the stopped queue after the first vehicle in the queue has been released. Note that some of the vehicles will not be forced to stop. The number of direction 1 vehicles per cycle that do not need to stop is

$$V_1[t_{c1} - (t_{c2} + 2t_t)V_1/R] .$$

Assuming constant arrival rates, the stopped delay per cycle in direction 1 is approximated as

$$1/2 \left\{(t_{c2} + 2t_t)(1 + \frac{V_1}{R})\right\}^2 V_1$$

The stopped delay time per cycle in direction 2 is obtained by substituting subscript 2 for 1 and vice versa. Then, the sum of the stopped delays in both directions is

$$\begin{aligned} \text{Stopped delay per cycle} = {} & 1/2 \left\{(t_{c2} + 2t_t)(1 + \frac{V_1}{R})\right\}^2 V_1 \\ & + 1/2 \left\{(t_{c1} + 2t_t)(1 + \frac{V_2}{R})\right\}^2 V_2 \end{aligned}$$

Eliminating t_{c1}, t_{c2} , and t_t using the previously developed expressions gives

$$\text{Stopped delay per cycle} = 1/2\ T^2 \left\{ V_1 \left[(1-\frac{V_1}{R})(1+\frac{V_1}{R}) \right]^2 + V_2 \left[(1-\frac{V_2}{R})(1+\frac{V_2}{R}) \right]^2 \right\}$$

Dividing this expression by T , the time per cycle, gives the delay expressed as vehicle-hours per hour. (This expression is applicable only for unsaturated flows.)

The value of R , the intersection capacity, was taken as (1300)(1.30) ≈ 1700 vph, where 1300 is an approximation for several geometrics applicable to construction zones and the factor, 1.3, adjusts for no turns. Moreover, t_t can be expressed as the quotient of the length of the one-way section (miles) and the speed of vehicles on a one-way section (mph). The program uses 30 mph as this speed.

The above expression can be further simplified. Let $V = V_1 + V_2$, the total of the two approach volumes. For the special case where $V_1 = V_2$,

$$\text{Stopped delay} = \frac{T}{2} \left\{ V[(1-\frac{V}{2R})(1+\frac{V}{2R})]^2 \right\} \text{ vehicle-hours/hour}$$

This represents a "worst case" as can be verified by examination of situations where $V_1 \neq V_2$. This is the case used in subsequent developments for <u>unsaturated flows</u>.

When vehicles arrive at a greater rate than can be served during the cycle, a queue forms. Under these conditions we treat the total queue in two parts. One is the queue to be served during the cycle, the served queue. The second is the wait queue--vehicles that must wait through one or more cycles.

The number of vehicles in the wait queue is the excess of arrivals over the number served at the saturation rate since oversaturation began. The number of such vehicles at any time, t , is

$$N_w(t) = \int_{t_o}^{t} [V(\tau) - V_s] d\tau$$

where $V(\tau)$ = Demand volume as function of time,

V_s = Saturation flow rate, and

t_o = Time when oversaturation began.

The stopped (or creeping) delay in the wait queue is

$$D_w(t) = \int_{t_o}^{t} N_w(t)dt \text{ vehicle-hours,}$$

where the integral is evaluated over all times when $N_w(t) \geq 0$. The total stopped delay accumulated during oversaturation is

$$D(t) = \int_{t_o}^{t} [D_{rs} + N_w(t)]dt$$

where D_{rs} = Rate (vehicle-hours/hour) that stopped delay is incurred in the served queue with saturated flows (T = 0.0833 hr), (Note that $D_{rs} = R(1-24t_t)$.)

b. Delay due to reduced speed: The reduced speed is 30 mph; otherwise the speed in rural areas would be $U = (50 - \frac{20}{2000} V)$ mph, where V = total of the two-way demands (vph).

This delay per vehicle is $\ell\left(\frac{1}{30} - \frac{1}{u}\right)$

where ℓ = length of one-way section (miles).

The total delay per hour due to reduced speed = $V\ell\left(\frac{1}{30} - \frac{1}{u}\right)$

Table 22 gives reduced speed delay factors for given demands.

TABLE 22

REDUCED SPEED DELAY FACTORS

Volume V (vph)	Normal Speed U (mph)	Delay/Mile $V\left(\frac{1}{30} - \frac{1}{U}\right)$ $\left(\frac{\text{Vehicle-Hours}}{\text{Hour Mile}}\right)$
0	50	0
200	48	2.5
400	46	4.636
800	42	7.616
1200	38	8.424
1600	34	6.272
1800	32	3.749
1900	31	2.043
2000	30	0

c. Total delay data: Using the delay equation developed for unsaturated conditions the two-direction sum of stopped delays was computed. This equation was used to compute delays at all volumes, since the definition of saturated conditions depends on travel time, t_t , and thus the length of the work site. If the volumes shown represent saturated or oversaturated conditions, the delays will of course be underestimated.

The computed values are plotted in Figures 12 and 13. In Figure 12 the values of delay due to reduced speeds were also added and the total is shown as a dashed curve. This latter delay was found to be important at volumes up to 1400 vehicles per hour, and is not included in Figure 12, which covers volumes of 1400 to 1700. The bottom curve is used for volumes of 1400 to 1620 and the top curve for volumes from 1630 to 1700.

The Highway Capacity Manual gives a breakdown of the average fraction of the ADT that can be expected during each hour of the day (Figure 3.6, p. 32). With this breakdown and the information from Figures D-2 and D-3 we can determine the daily delay for rural or urban conditions under a number of construction schedules.

Figure 14 gives the computed delay versus ADT for schedule R-1 (lane closed 24 hr per day) or R-2 (lane closed 8 AM to 4 PM). Also shown are equations developed by curve fitting.

Figure 15 gives the delay versus ADT under schedules U-1 (lane closed 24 hr per day), U-2 (lane closed all hours except 6 to 8 AM and 3 to 6 PM), and U-3 (lane closed 8 AM to 3 PM). Again, equations developed by curve fitting are given.

3. Development of delay formulas for multilane highways: Several construction zone configurations are commonly used on multilane highways. Four configurations considered here are shown in Figure 16.

The vehicle-hours of delay in multilane construction zones arise from reduced speed and queuing. When queuing occurs, delays result from the stopped delay of vehicles and the reduced speed that the vehicles travel when going through the zone.

a. Reduced speeds: When capacity is not exceeded the delays are due entirely to reduced speeds. Let E be the delay vehicle-hours/hour) due to reduced speeds.

$$E = \ell\left(\frac{1}{u_r} - \frac{1}{u_n}\right)$$

where ℓ = Construction zone length (miles) + 0.20

u_r = Reduced speed in zone, and

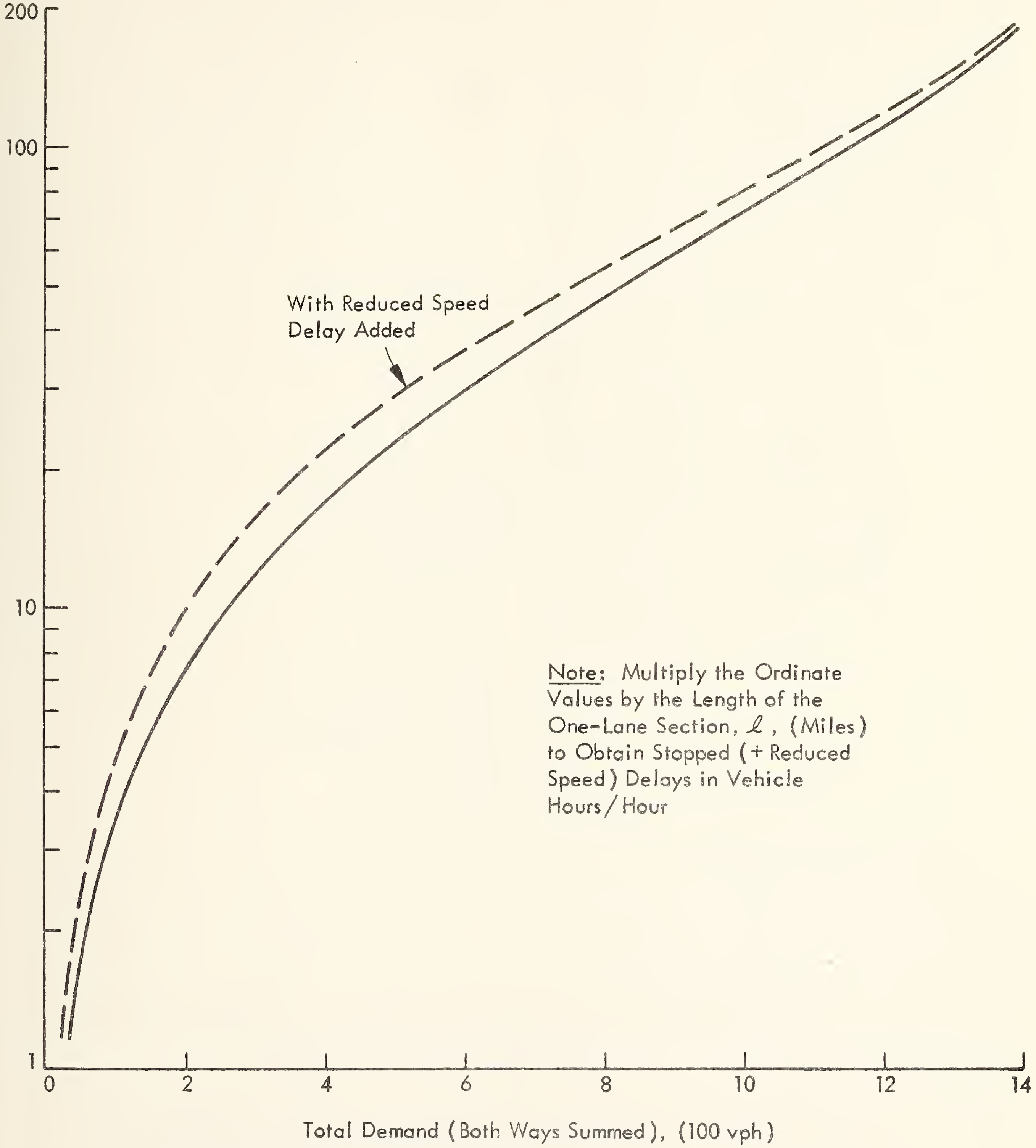


Figure 12 - Stopped Delays, Configuration 1 for Volumes up to 1,400 vph

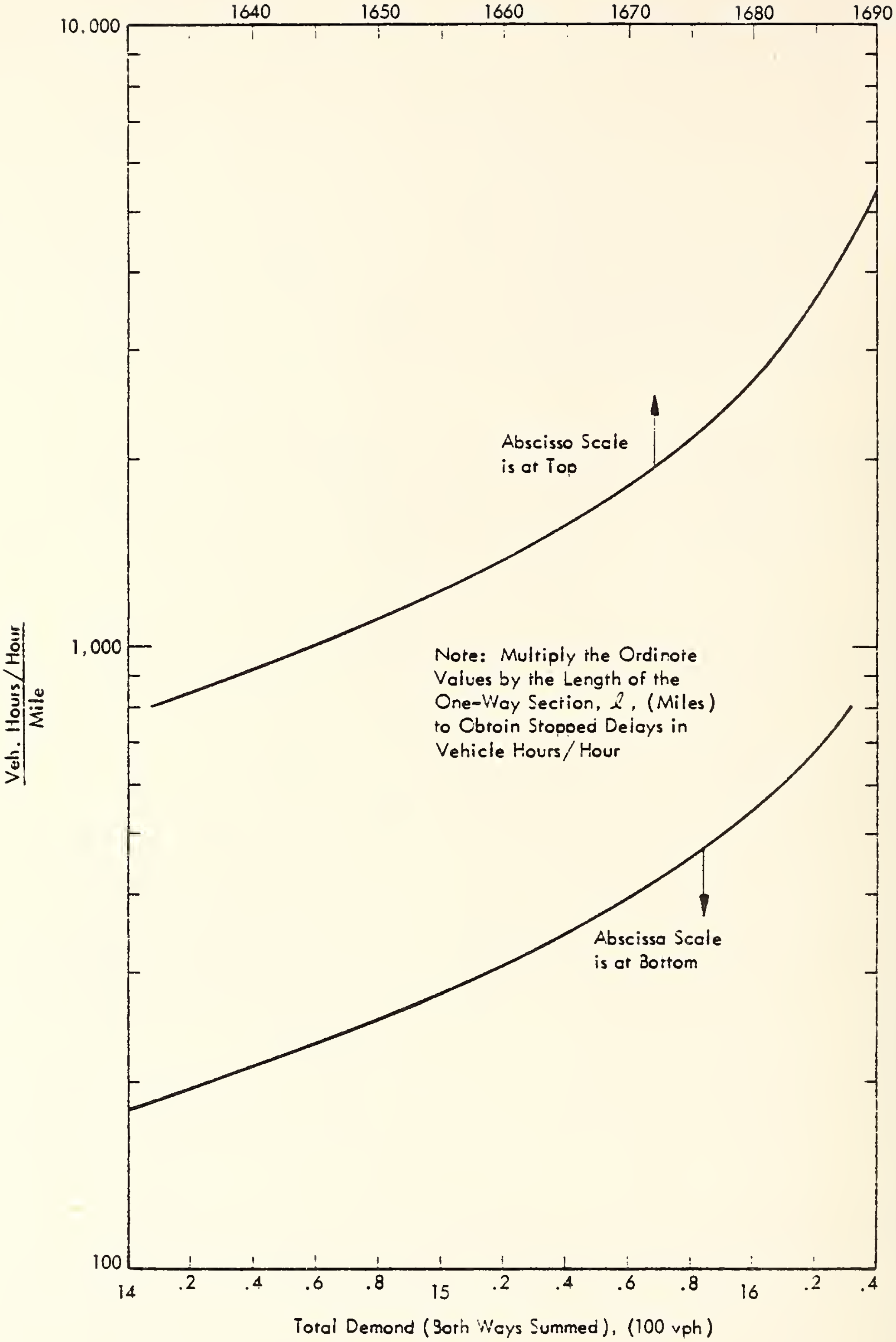


Figure 13 - Stopped Delays, Configuration 1 for Volumes of 1,400 to 1,700 vph

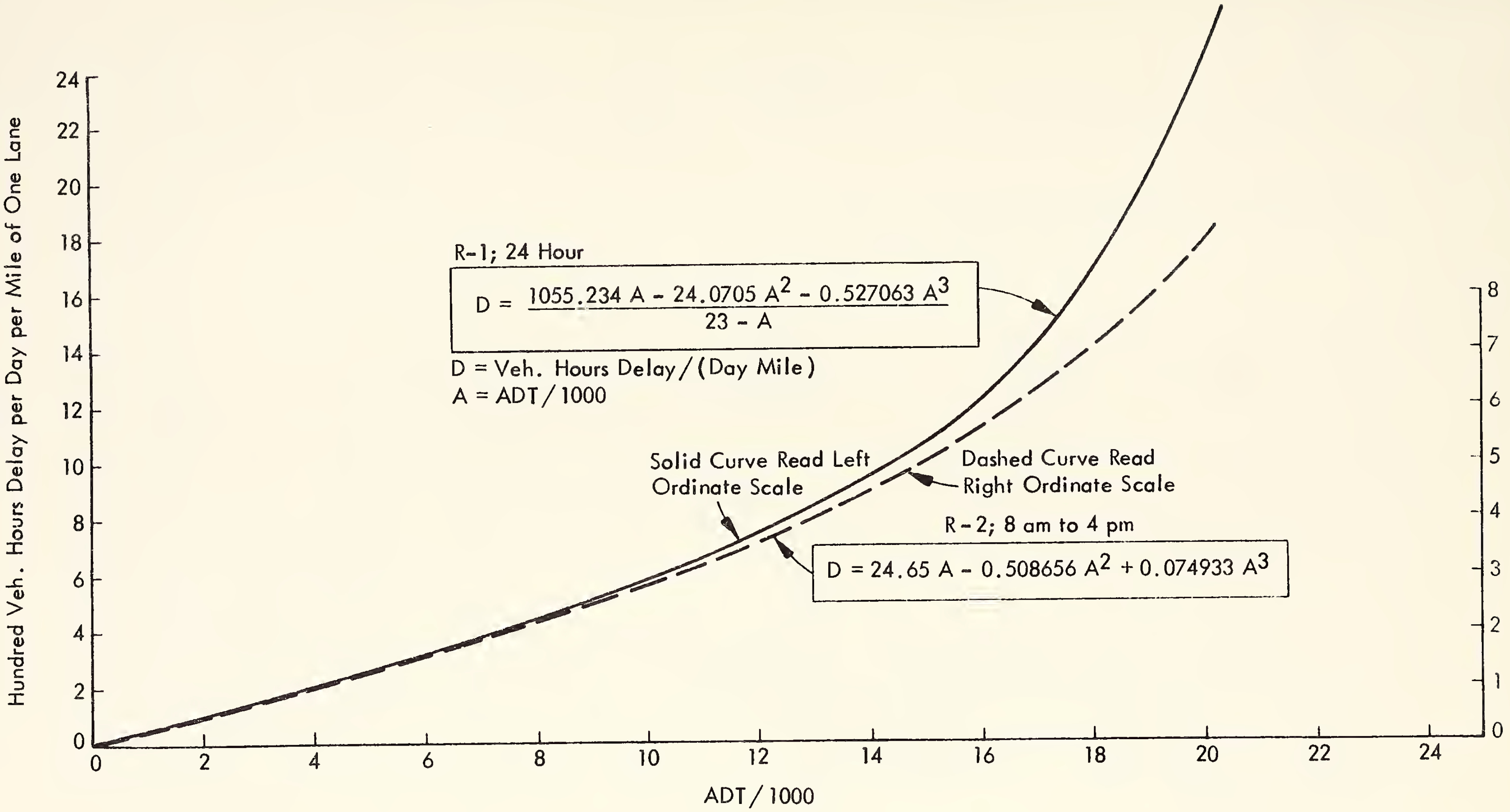


Figure 14 - Stopped Delays, Configuration 1, Rural

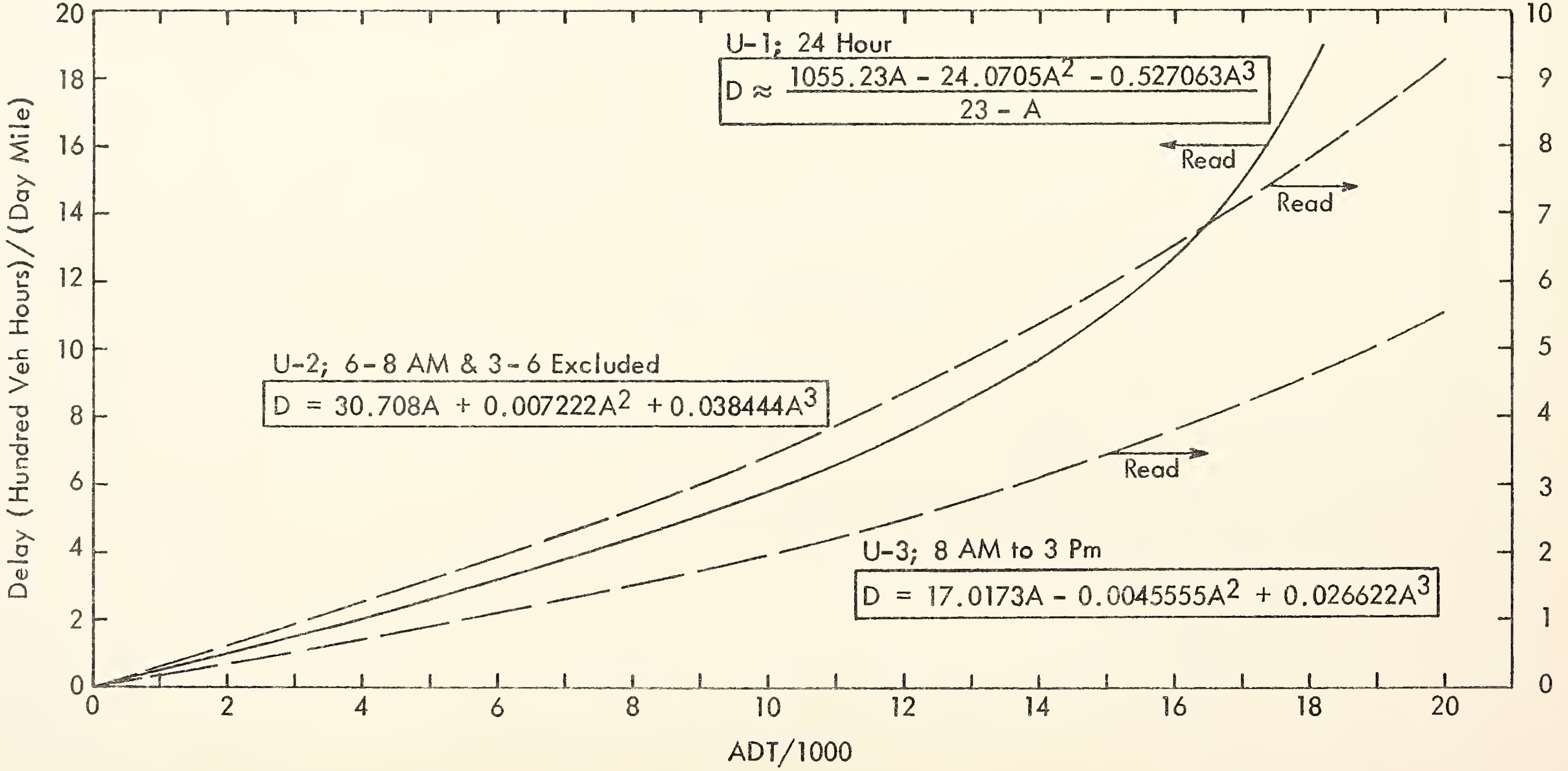
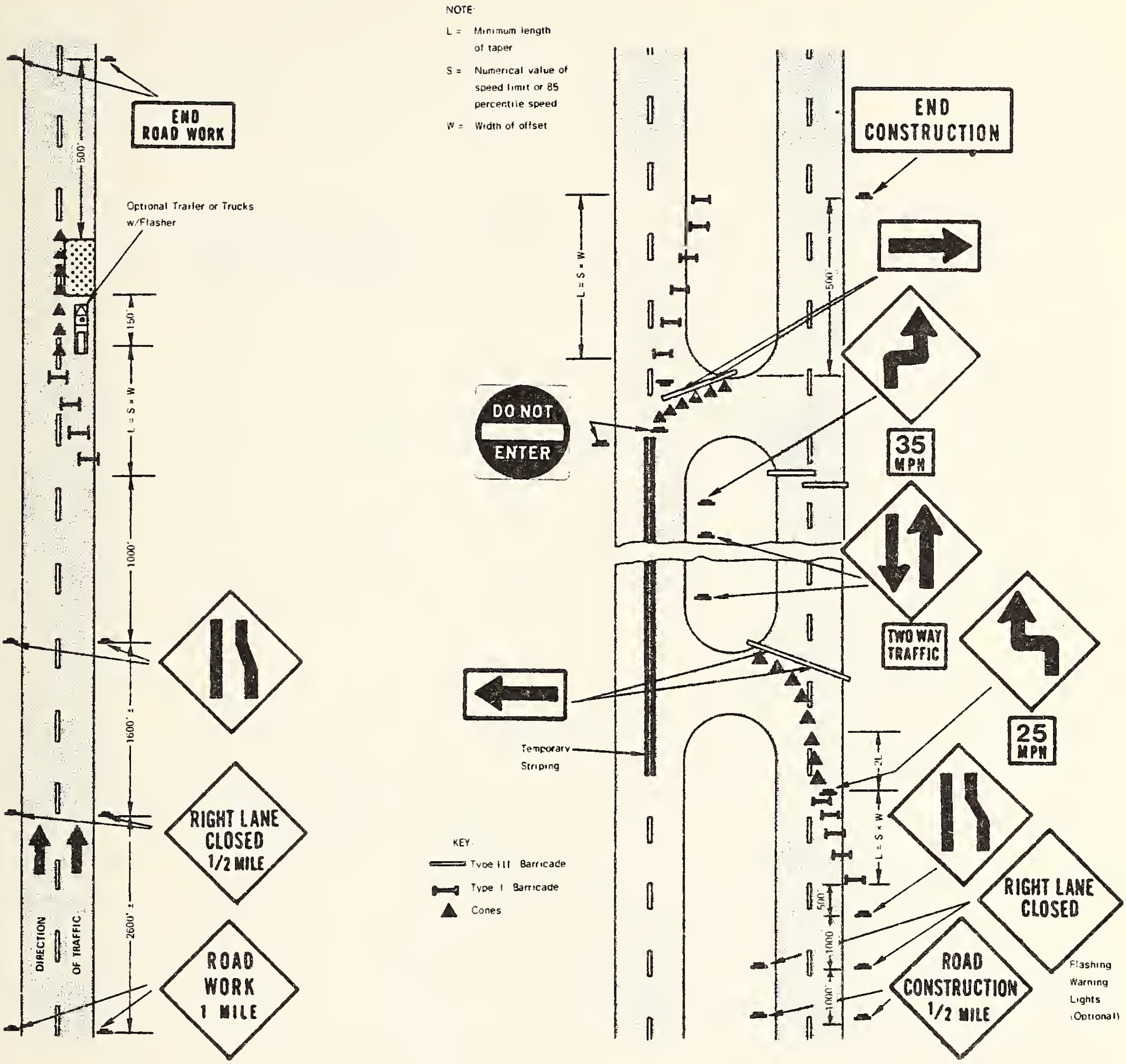


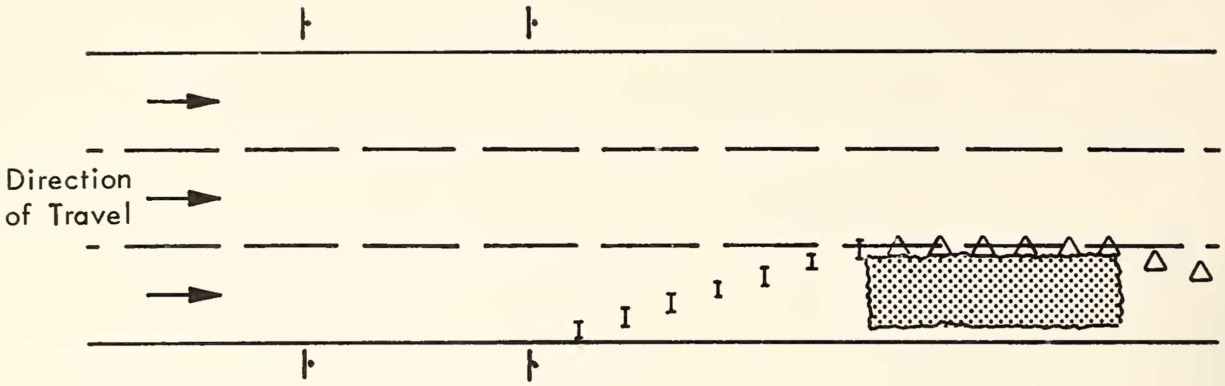
Figure 15 - Stopped Delays, Configuration 1, Urban



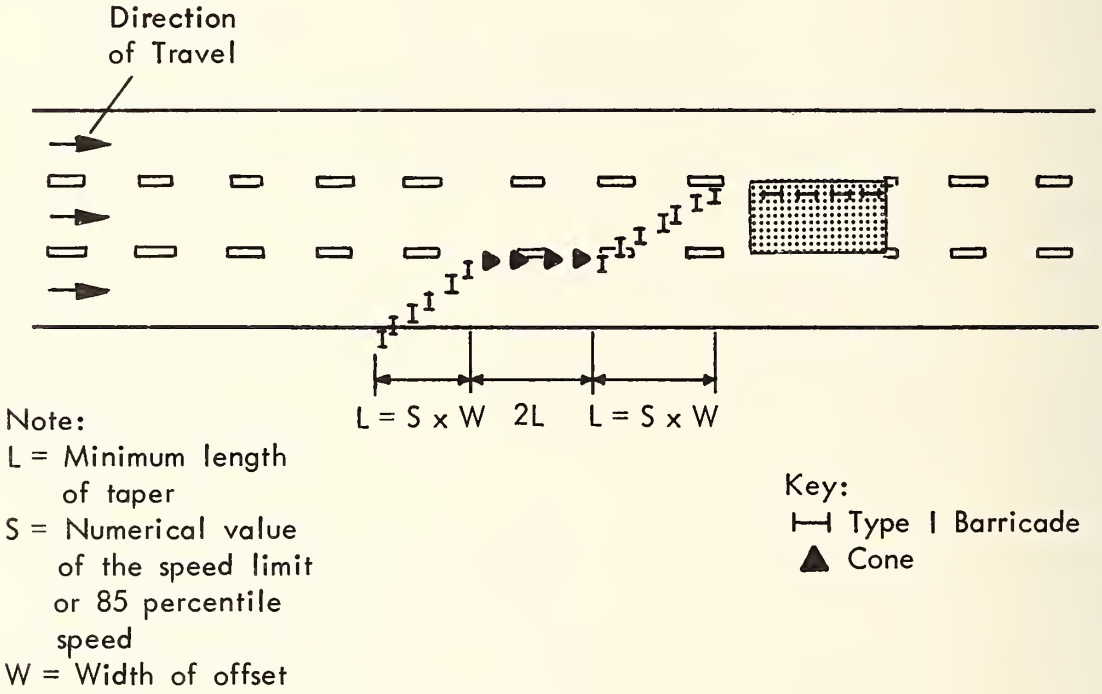
Two Unidirectional Lanes
Reduced to One Lane
(Configuration 2)

Two-way Four Lane Divided Highway
Reduced to Two-way Two Lane
(Configuration 3)

Figure 16 - Multilane Construction Zone Configurations



Three Unidirectional Lanes Reduced to Two Lane
(Configuration 4)



Note:
L = Minimum length of taper
S = Numerical value of the speed limit or 85 percentile speed
W = Width of offset

Three Unidirectional Lanes Reduced to One Lane
(Configuration 5)

Figure 16 (concluded)

u_n = Normal speed in zone.

The value, 0.20, is used as the average length of the taper, and u_r and u_n depend on the volume, V , which is less than capacity.

Figure 17 shows the speeds of vehicles in the various configurations and during normal roadway operation. During the time queues are present u_n will depend on demand volume but u_r will be 30 mph for capacity flow conditions in the construction zone. Thus, the delay from reduced speeds when a queue is present is $E = \ell(1/30 - 1/u_n)$.

Using the above formula and the general data on hourly volumes and vehicle population given earlier, a representation of the delay in two unidirectional lanes reduced to one lane (configuration 2) was developed. The process used may be explained easily by an example. Referring to curve 1 in Figure 17, the normal average speed u_n in a zone at one-eighth of capacity (0.125) would be 55 mph. Using curve 3 in Figure 17, the reduced average speed u_r would be 50. The last two columns of Table 23 gives the results of calculations of delays, with and without queue dissipation, for various volumes. A plot of the information in Table 23 is shown in Figure 18.

Figure 18 and the traffic demands in 1-hr periods of a day (from the Highway Capacity Manual) were then used to develop the hourly vehicle delays experienced in each mile of a construction zone due to reduced speeds. Figure 19 is a plot of this information for schedules U-1, U-2 and U-3 (see Table 17).

In Figure 19 the coefficients are given for the best fit for each of the curves. These three curves represent the total delay for all times except when there are queues present. For example, on the U-1 curve the ADT where queues could be expected during some hours of the day ($V > 2,000$) is 23,000. This means that, for the U-1 schedule, stopped delay must be added for ADT's greater than 23,000. Thus, the U-1 coefficients shown can be used for ADT's ≤ 23,000. For the U-2 and U-3 curves, queues can be expected for ADT's of 35,000 and above.

b. Stopped delays: When queues are present, delays from stoppage in queues must be added to reduced speeds during queue dissipation. The computed values for these additional delays are shown in Table 24. The value for stopped delays (ΔD_{wi}) was computed for each hour that queues are present from the formula:

$$\Delta D_{wi} = N_{io} (\Delta t) + (V_i - V_s)\frac{(\Delta t)^2}{2} ,$$

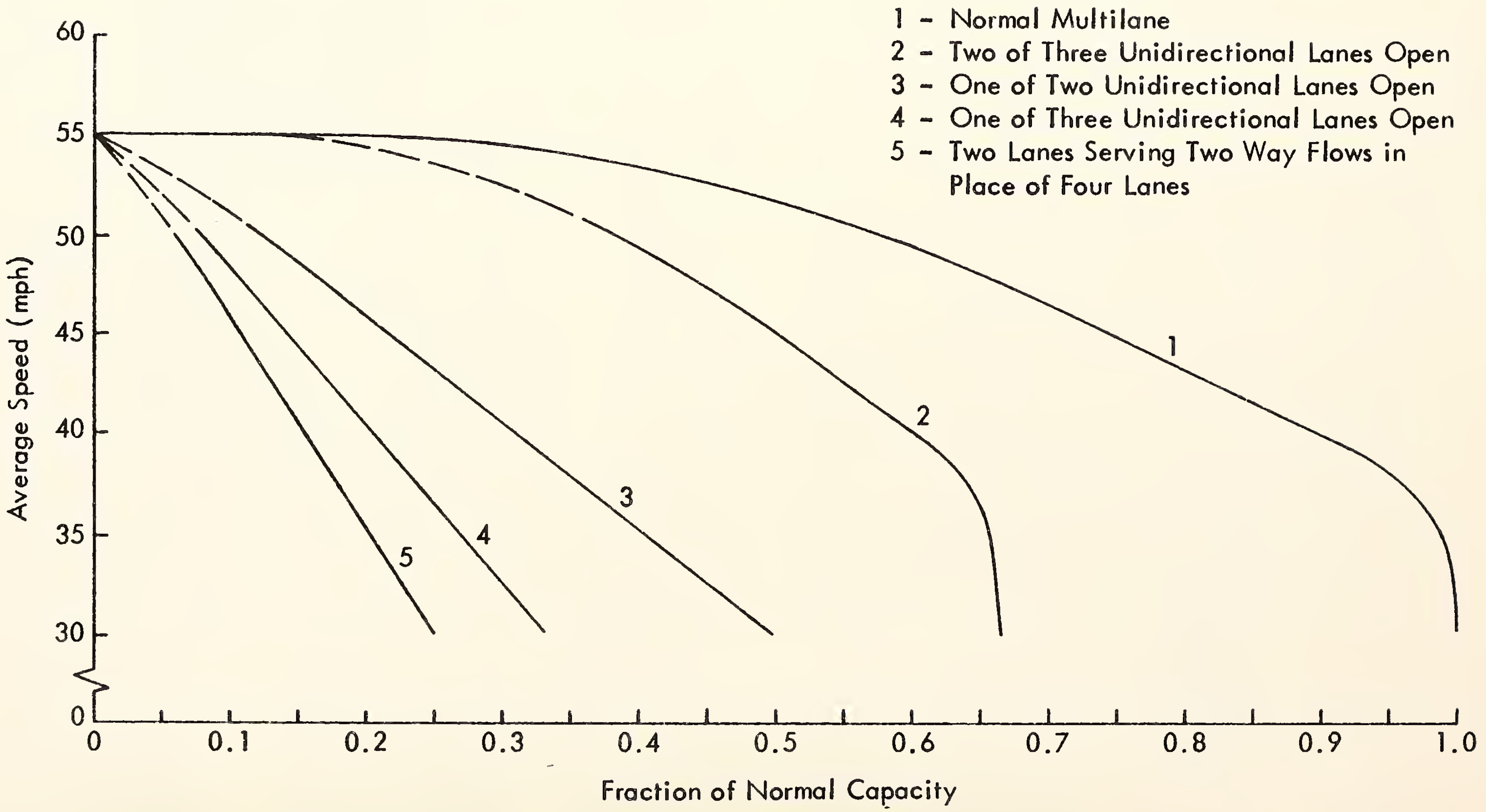


Figure 17 - Speed Capacity Relationships, Multilane Facilities

TABLE 23

DELAYS FROM REDUCED SPEEDS (CONFIGURATION 2)

Fraction of Normal Capacity	Volume V (vph)	Reduced Speed U_r (mph)	Normal Speed U_n (mph)	Delay $\left(\frac{1}{U_r} - \frac{1}{U_n}\right) V$ $\left(\frac{\text{Vehicle-Hours}}{\text{Hour Mile}}\right)$	Delay During Queue Dissipation $\left(\frac{1}{U_r} - \frac{1}{U_n}\right) V$ With $U_n = 30$
0	0	50	55	0	0
0.125	500	50	55	0.9091	7.576
0.200	800	46	55	2.8458	12.121
0.300	1200	40.6	54.4	7.4978	17.941
0.400	1600	35.3	53.3	15.3070	23.315
0.500	2000	30.0	51.6	27.9070	Queue is not dissipating for these volumes.
0.600	2400	30.0	49.3	31.3186	
0.700	2800	30.0	46.4	32.9885	
0.800	3200	30.0	43.3	32.7635	
0.900	3600	30.0	39.9	29.7745	
0.950	3800	30.0	38.0	26.6665	
0.980	3920	30.0	36.0	21.7780	
0.990	3960	30.0	34.8	18.2069	
1.000	4000	30.0	30.0	0	

Notes: Capacity flow, V_s, taken as 2000 vph.
For $V > 2000$ vph, queue will increase.
After queue is normal but $V < 2000$ vph, U_n will remain at 30 mph until queue dissipates.

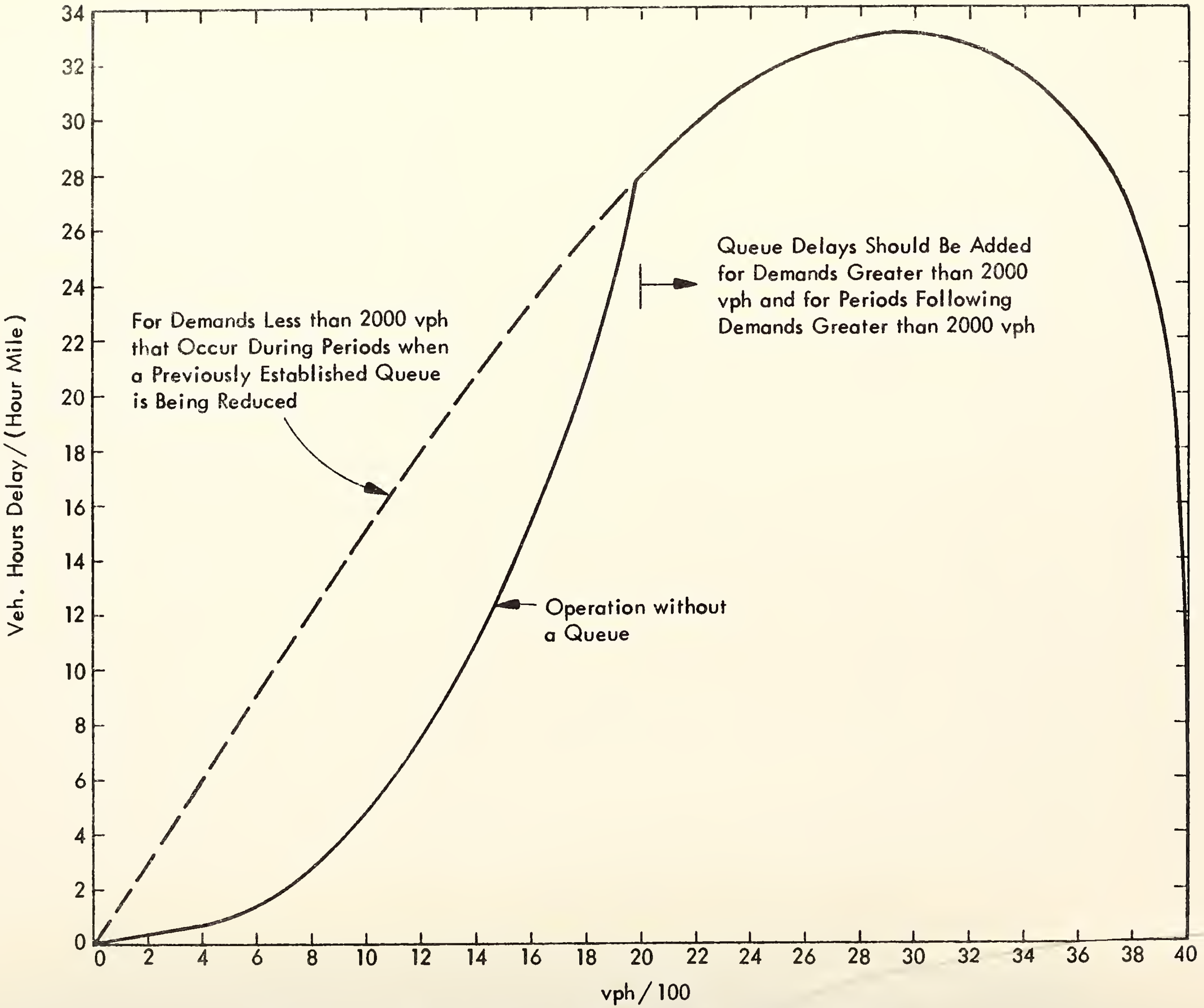
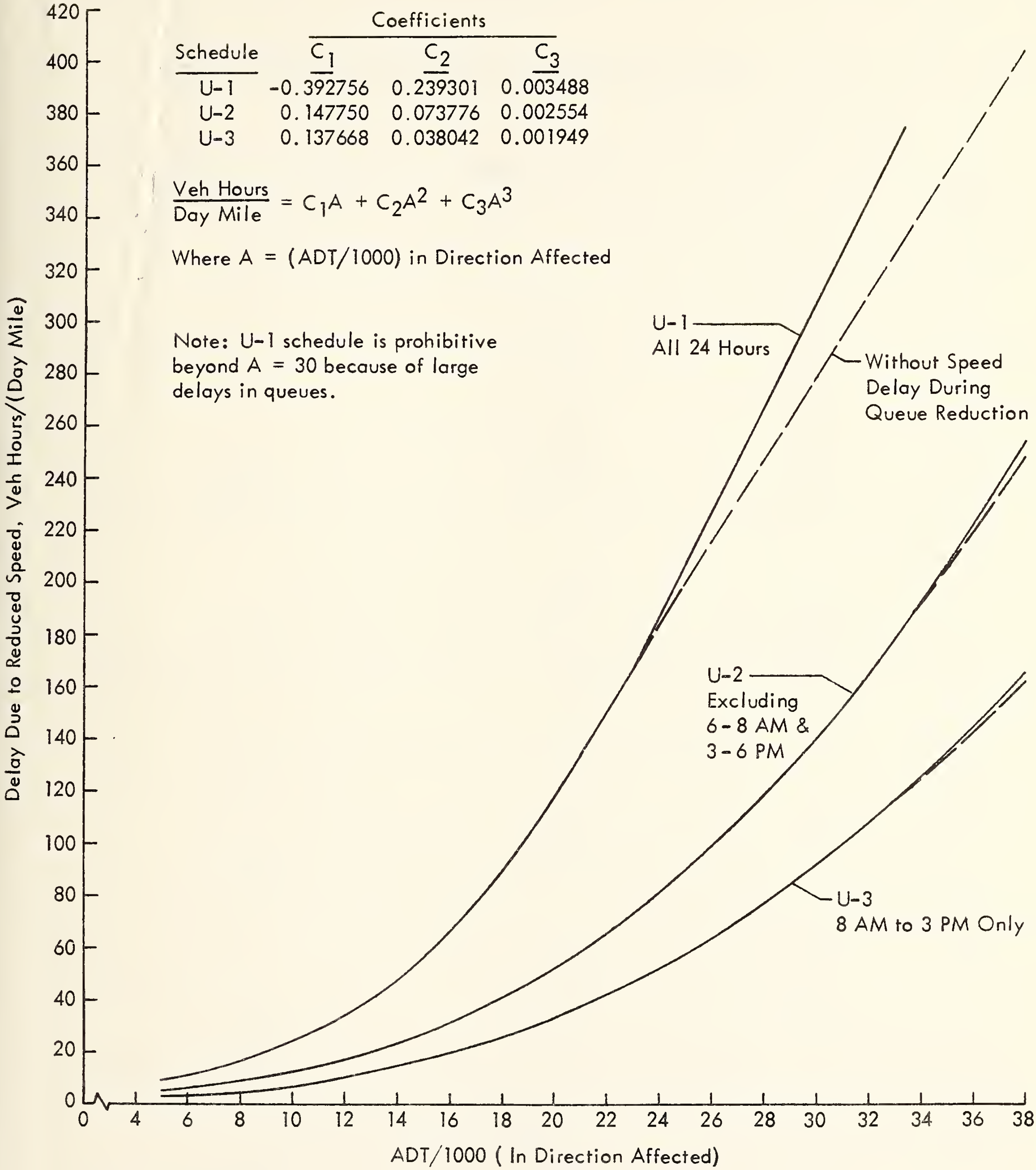


Figure 18 - Vehicle-Hours of Delay Due to Reduced Speeds
(Configuration 2)



Schedule	Coefficients C_1	C_2	C_3
U-1	-0.392756	0.239301	0.003488
U-2	0.147750	0.073776	0.002554
U-3	0.137668	0.038042	0.001949

$$\frac{\text{Veh Hours}}{\text{Day Mile}} = C_1A + C_2A^2 + C_3A^3$$

Where A = (ADT/1000) in Direction Affected

Note: U-1 schedule is prohibitive beyond A = 30 because of large delays in queues.

Figure 19 - Delays Due to Reduced Speeds, Configuration 2, Urban

TABLE 24

DELAYS DUE TO STOPPAGE IN QUEUES AND REDUCED SPEEDS DURING QUEUE DISSIPATION FOR CONFIGURATION 2

Hour	Demand Hour Volume (vehicle/hour)	Stopped Delay in Queues ΔD_W (vehicle-hour)	Delay Due to Reduced Speeds During Queue Dissipation (vehicle-hour/mile)
ADT = 28,000 (U-1) (Note, effect on U-1 starts at 23,000 ADT.)			
7-8	2,128	64.0	
8-9	1,568	18.96	2.52
15-16	2,156	78.0	
16-17	2,436	374.0	
17-18	2,156	670.0	
18-19	1,484	490.0	9.30
19-20	1,344	41.02	3.54
		1,735.98	15.36
ADT = 33,000 (U-1)			
7-8	2,508	254.0	
8-9	1,848	432.0	3.95
9-10	1,485	123.04	6.36
15-16	2,541	270.5	
16-17	2,871	976.5	
17-18	2,541	1,669.0	
18-19	1,749	1,827.5	5.90
19-20	1,584	1,494.0	8.30
20-21	1,287	929.5	10.20
21-22	1,221	210.74	7.69
		8,186.78	42.40
ADT = 38,000 (U-3) (Note, effect on U-2 and U-3 starts at 35,090 ADT)			
8-9	2,128	64	
9-10	1,710	28.25	2.93
14-15	2,166	83.0	
15-16	2,926	12.83	1.95
		188.08	4.88
ADT = 38,000 (U-2 = U-3 from above, plus.)			
18-19	2,014	7.00	
19-20	1,824	0.56	0.37
		195.64	5.25

where N_{io} = Number of queued vehicles at the beginning of the i^{th} time intervals,

Δt = Duration of time interval (hours),

V_i = Demand (vph) during i^{th} time interval, and

V_s = Saturation (or capacity) flow (vph).

Moreover, $N_{io} = N_{(i-1)o} + (V_{i-1} - V_s)(\Delta t)$, and

$N_{(i+1)o} = N_{io} + (V_i - V_s)(\Delta t)$

During the interval that the queue dissipates,

$$\Delta t = \frac{N_{io}}{V_s - V_i}$$

and the stopped delay during that interval is:

$$N_{io}\ (\Delta t) + (V_i - V_s)\ \frac{(\Delta t)^2}{2} = \frac{(N_{io})^2}{2(V_s - V_i)}$$

The reduced speeds during the queue dissipation $(\Delta E_{i/\ell})$ are computed exactly as the delays due to reduced speeds except that u_r is always equal to 30 mph.

Approximating the values of ΔD_{wi} with a quadratic leads to the following forms:

U-1: $\Delta D_{wi} = 39675 - 3450A + 75A^2$; $A > 23$,

U-2: $\Delta D_{wi} = 28175 - 1610A + 23A^2$; $A > 35$, and

U-3: $\Delta D_{wi} = 52307 - 2989A + 42.7A^2$; $A > 35$

where

$$A = ADT/1000$$

Formulas for the R-1 and R-2 schedules can be approximated by using the U-1 coefficients for R-1 schedule and the U-3 coefficients for the R-2 schedule.

The addition of the formulas for stopped delay and the formulas for delay due to reduced speed result in the following form that approximates the total delay D:

where $D = C_o + C_1A + C_2A^2 + C_3A^3$

D = Vehicle-hours of delay per day, and

A = ADT/1000 (ADT in the direction affected).

These are the coefficients given in Table 21.

4. Development of formulas for excess fuel consumption: Fuel costs are the major component of increased operating expense and are the only costs treated here. Fuel costs can be affected by up to three factors. The first is a speed change cycle from the normal speed to a stop and back to normal speed. (This is applied for each vehicle although some will not need to stop.) The second is fuel consumed during idling while in the stopped delay. The third is the fuel consumed in traversing the construction zone minus the fuel that would have been used at normal speed. Note that the contributions of the individual factors may be negative.

In order to compute the excess amount of fuel consumed for various conditions, it was necessary to specify the percentage of passenger cars and trucks in the vehicle population. The specified vehicle population is 90% - passenger cars, 1% - 5,000 lb delivery trucks, 2% - 12,000 lb single unit trucks, and 7% - 40,000 lb gasoline-powered semitrailers or 50,000 lb diesel-powered semitrailers.

a. Excess fuel consumption formula for two-lane, two-way highway reduced to one-lane of alternating traffic: Table 25 presents data needed to compute the excess fuel consumption due to speed change cycles and due to reduced speeds. Information in this table and the hourly volume data referenced earlier were used to compute the excess fuel consumed, plotted in Figure 20.

The fuel consumption due to stopped delay is 0.376 gal. for every vehicle hour of stopped delay.

By combining equations that approximate the curves for excess fuel consumption due to speed change cycles and reduced speed plus the relationship for fuel consumption due to stopped delay we can determine the following formula for excess fuel consumed:

$$G = C_1A + C_2A^2 + C_3A^3 + C_ID$$

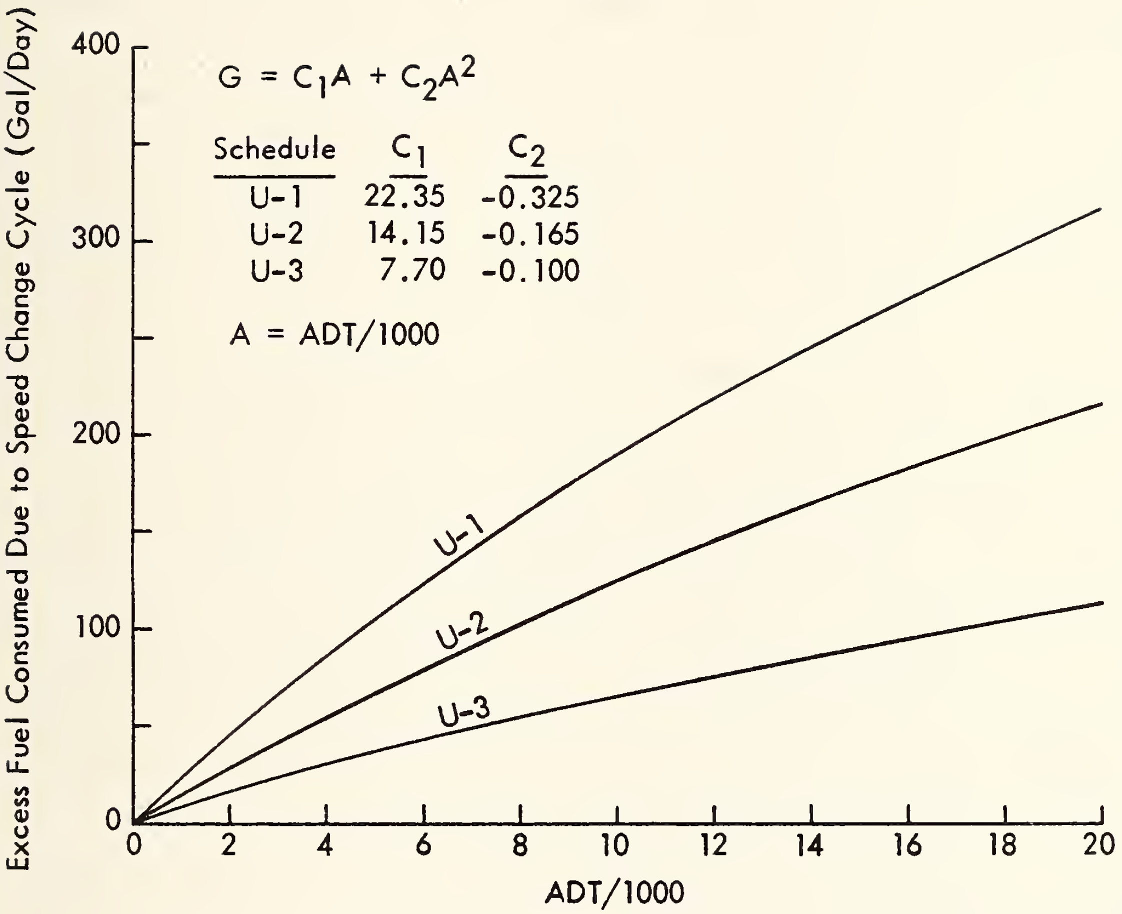
where

G = Excess gallons of fuel consumed per day,

A = ADT/1,000 (both directions summed),

C_I = Average consumption at idle, gallons/vehicle hour, and

D = Vehicle hours of delay per day.

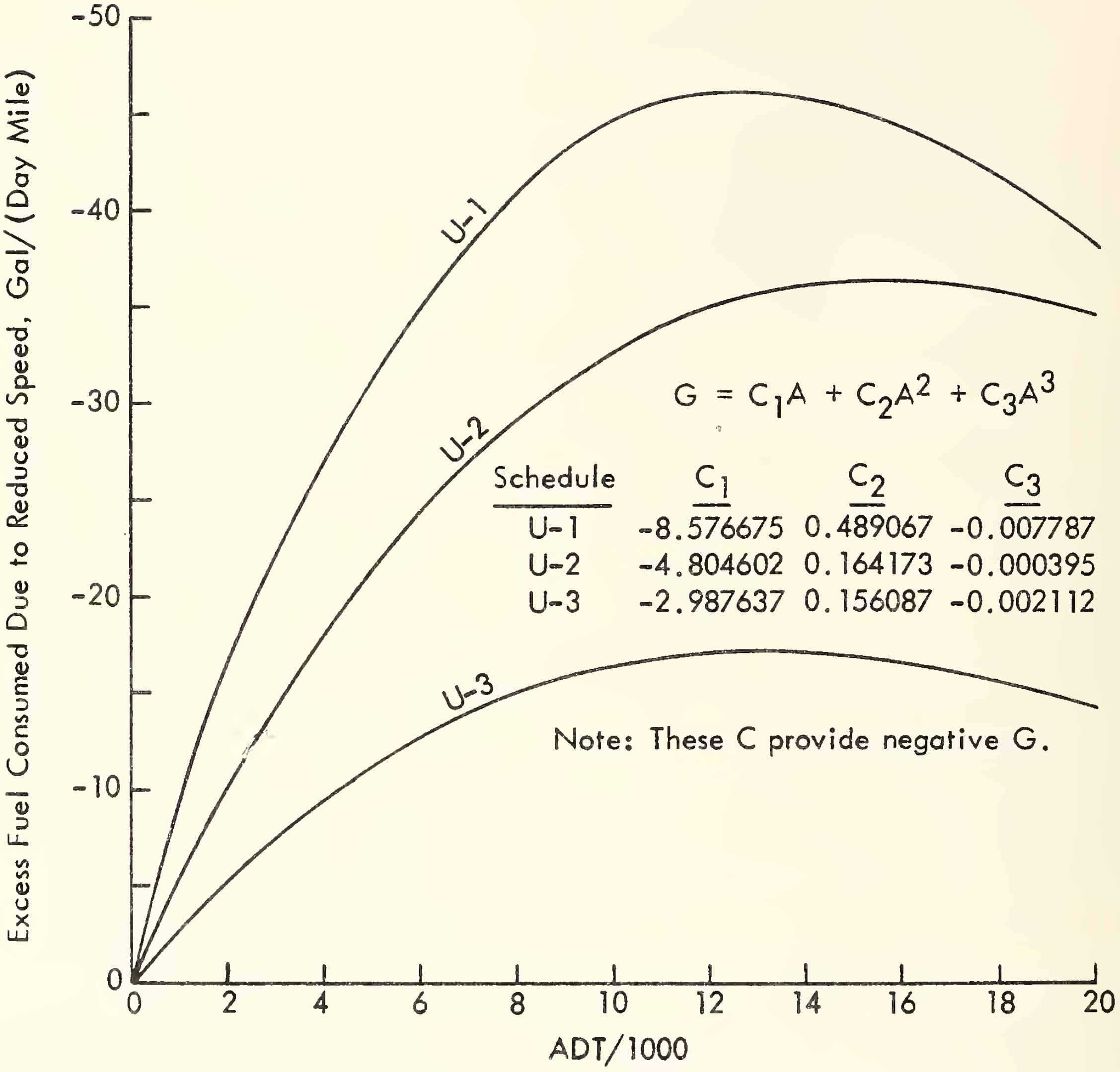


$$G = C_1A + C_2A^2$$

Schedule	C_1	C_2
U-1	22.35	-0.325
U-2	14.15	-0.165
U-3	7.70	-0.100

A = ADT/1000

Figure 20 - Excess Fuel Consumption, Configuration 1, Urban



$$G = C_1 A + C_2 A^2 + C_3 A^3$$

Schedule	C_1	C_2	C_3
U-1	-8.576675	0.489067	-0.007787
U-2	-4.804602	0.164173	-0.000395
U-3	-2.987637	0.156087	-0.002112

Note: These C provide negative G.

Figure 20 (concluded)

TABLE 25

EXCESS FUEL CONSUMPTION, CONFIGURATION 1

Volume V (vph)	Normal Speed U_n (mph)	Excess Consumption Due to Speed Change Cycles (gal/hr)	Excess Consumption Due to Reduced Speed (gal/hr-mile)
0	50	0	0
200	48	4.26	-1.38
400	46	8.00	-2.16
800	42	14.08	-2.40
1,200	38	18.36	-1.56
1,600	34	21.12	-0.32
1,800	32	21.78	0
2,000	30	22.20	0

Table D-3 gives the coefficient values.

b. Excess fuel consumption formula for two unidirectional lanes reduced to one unidirectional lane (Configuration 2): On multilane highways during periods when there is no queuing added fuel consumption arises from only two sources, a speed change cycle between the normal and reduced speed, and traversing the zone at a reduced speed. When queues are formed or are dissipating, all three factors are involved: a speed cycle from normal speed to stop and then back to normal; a lower than normal speed in the zone of 30 mph; and the fuel consumed during idling for the vehicle hours in queue. (Actually, the time in queues is spent at intermittant speeds less than 30 mph. This is a much higher fuel consumption condition than would occur during normal travel through the queue length. We approximate the difference by the idle consumption during time in the queue.)

Figure 21 gives the excess fuel consumption due to speed change cycles. The dashed line includes the excess fuel consumed when queues formed in previous hours are being dissipated. Figure 22 gives the excess fuel consumption due to reduced speeds. During queue dissipation the reduced speed, u_r, is always equal to 30 mph. This effect is accounted for in the dashed line in Figure 22.

The information shown in Figures 21 and 22 was used along with the hourly volume breakdown in the Highway Capacity Manual to compute the data shown in Figure 23. Equations were determined that approximate each of the curves shown. (The equations are given in Figure 23.)

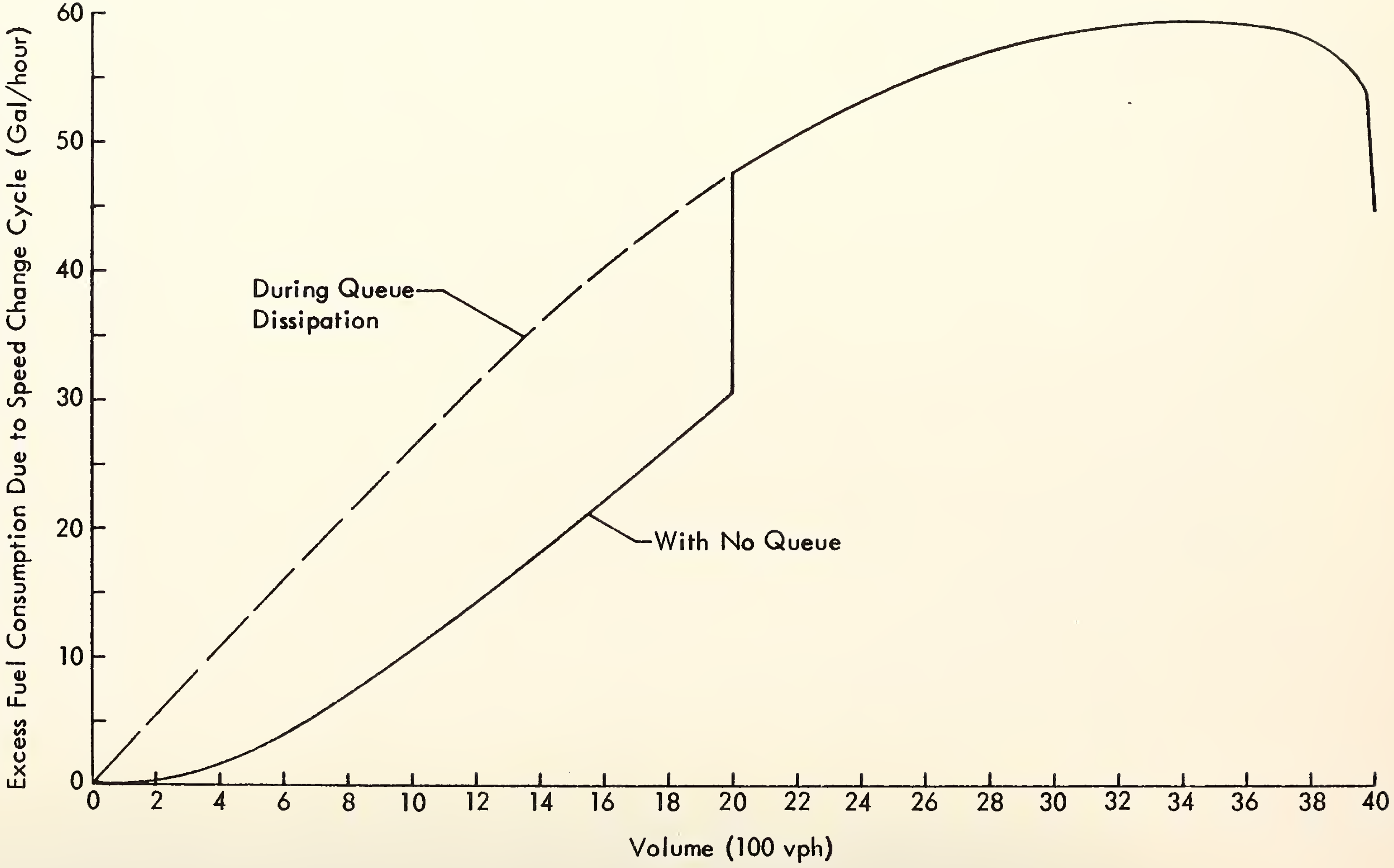


Figure 21 - Excess Fuel Consumption Due to Speed Change Cycles, Configuration 2

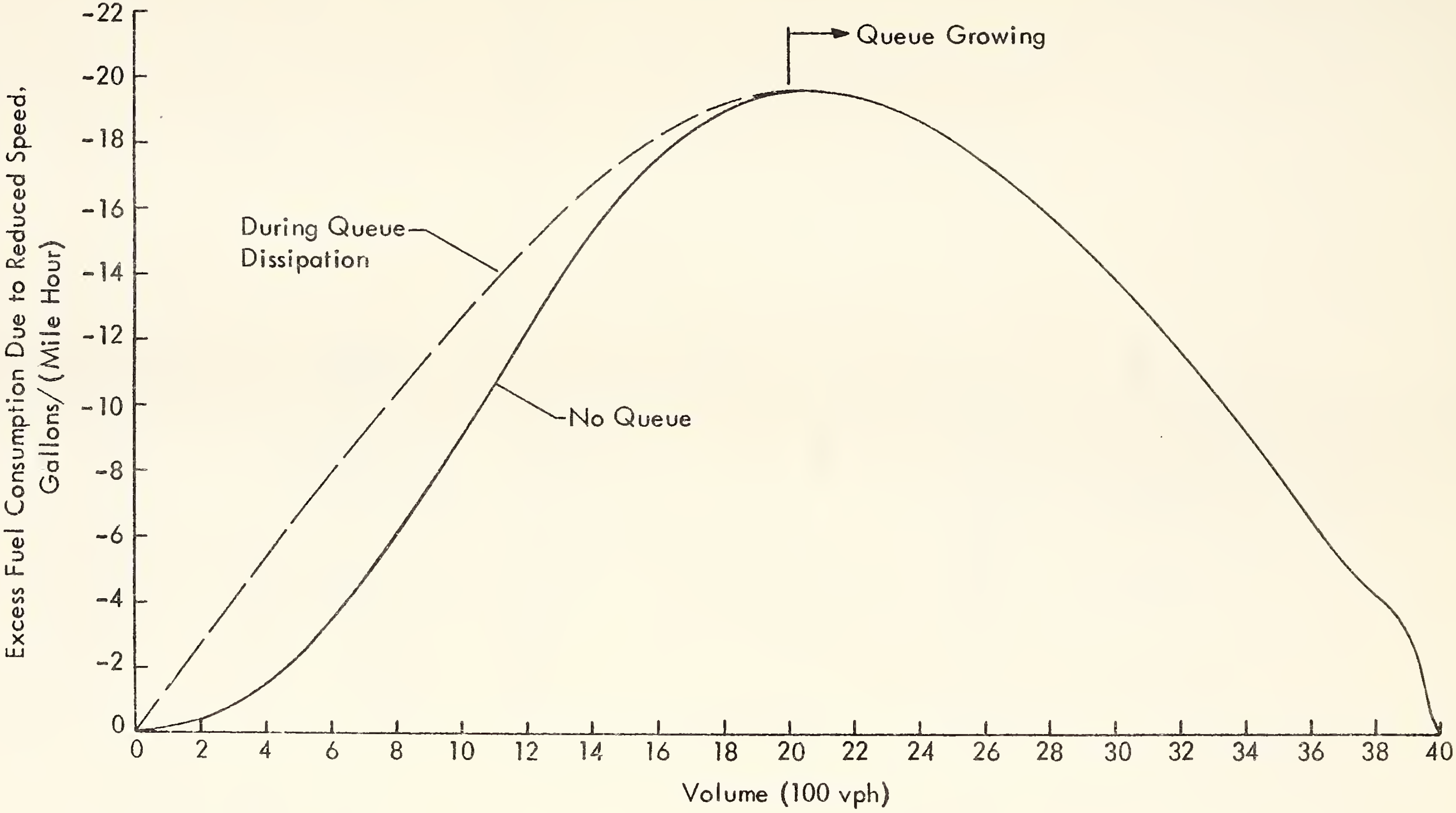
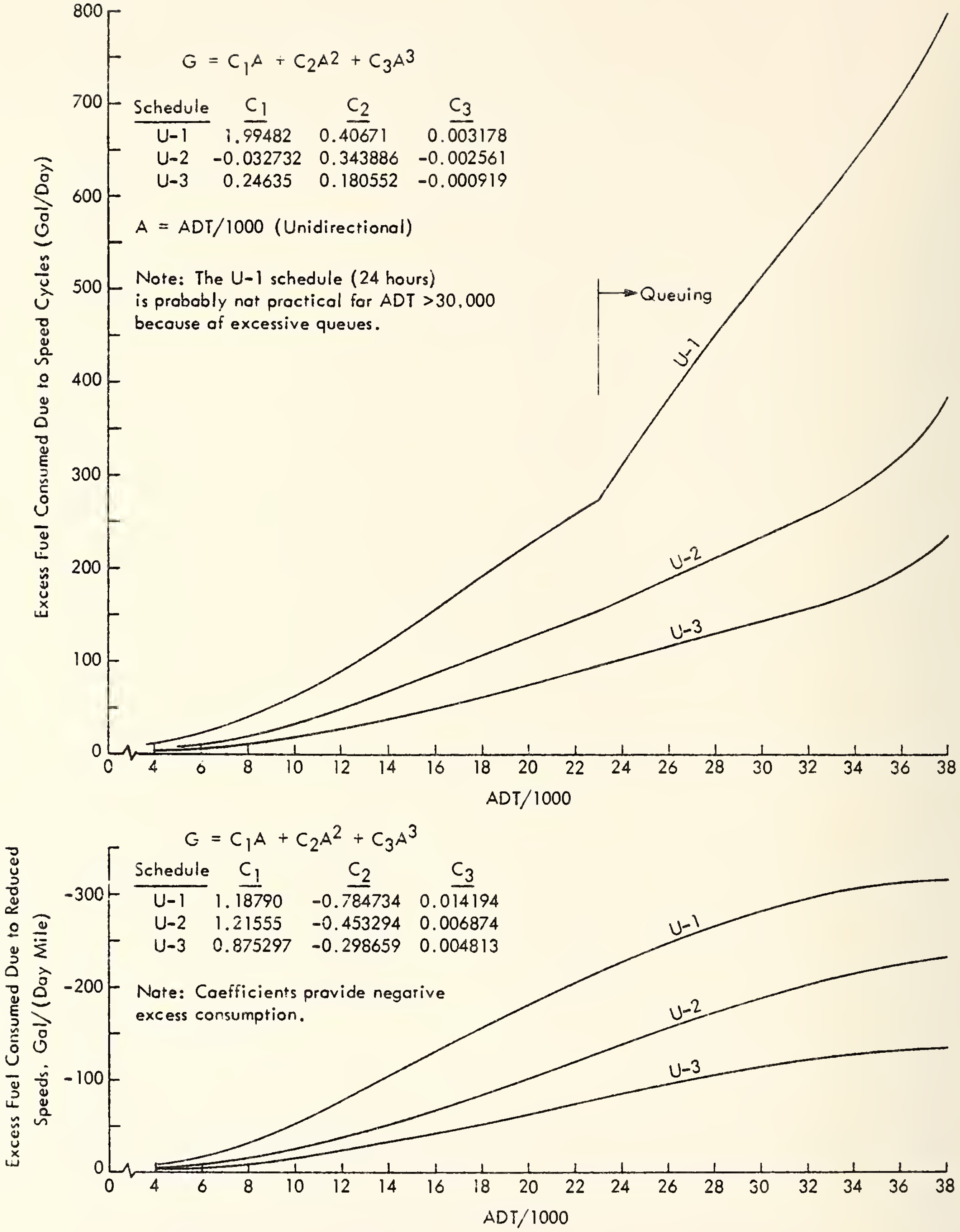


Figure 22 - Excess Fuel Consumption Due to Reduced Speed, Configuration 2



$$G = C_1A + C_2A^2 + C_3A^3$$

Schedule	C_1	C_2	C_3
U-1	1.99482	0.40671	0.003178
U-2	-0.032732	0.343886	-0.002561
U-3	0.24635	0.180552	-0.000919

A = ADT/1000 (Unidirectional)

Note: The U-1 schedule (24 hours) is probably not practical for ADT >30,000 because of excessive queues.

$$G = C_1A + C_2A^2 + C_3A^3$$

Schedule	C_1	C_2	C_3
U-1	1.18790	-0.784734	0.014194
U-2	1.21555	-0.453294	0.006874
U-3	0.875297	-0.298659	0.004813

Note: Coefficients provide negative excess consumption.

Figure 23 - Excess Fuel Consumed, Configuration 2

To obtain the total excess fuel consumed, the two equations for each schedule that are given in Figure D-13 are combined. Also, when queues are present the fuel consumed idling for the vehicle-hours in queue must also be added. The vehicle-hours in queue were determined as part of the delay computation for this configuration (Section D.3.b). This figure was combined with the two previous equations for each schedule to give the excess fuel consumed for two unidirectional lanes reduced to one lane. The equation is:

$$G = C_o + C_1A + C_2A^2 + C_3A^3$$

where

G = Excess fuel consumed (gallons/day), and

A = ADT/1,000 (ADT in direction affected)

Table D-5 provides the coefficient values.

APPENDIX E

FLOW DIAGRAMS AND SPECIFICATIONS FOR BENEFIT-COST PROGRAM

This appendix presents the flow diagrams and specifications used to program the benefit-cost model. The overall benefit-cost flow diagram, presented as Figure 3 in the text, is repeated here to place the following discussion in context. Then, the flow diagrams for each subroutine in the program are individually presented and discussed.

A. Benefit-Cost Flow Diagram

The benefit-cost flow diagram is shown in Figure 24. The notes on the figure explain the nature of the computations executed at each stage of the analysis. One pass through the logic diagrammed in the figure completes the benefit-cost analyses of all requested countermeasures at one highway site or section. Until the call to subroutine EFEAS each routine deals with one aspect of each countermeasure requested. In EFEAS and PFRM each requested and feasible countermeasure is evaluated for its benefit/cost ratio and a three line set of printed output is generated.

Figure 24 contains one feature that is not included in the current version of the model. The main element of this feature is subroutine SIG, which makes a calculation to determine if "significant" savings in accident costs are possible. No method for making this calculation is available at present. The calculations and test for significant savings in accident costs are bypassed when the default values of zero are retained for CFAS and CCAS.

B. Subroutines PREP1 and PREP2

Subroutine PREP1 is diagrammed in Figure 25. This routine initializes variables, sets default values, and if necessary reads data files into memory. Only a few of the variables that are initialized are illustrated in the flow diagram. The remainder are listed in Table 26.

Subroutine PREP2 is diagrammed in Figure 26. This routine tests the input data to determine that all mandatory input values have been supplied. If mandatory data are omitted by the user, an appropriate error message is printed. Two of the input tests are illustrated in the flow diagram and the remainder are listed in Table 27. Subroutine PREP2 also sets initial values for a set of subscripted variables listed in the flow diagram.

C. Subroutine REED

The purpose of subroutine REED is to read the input data provided by the user. Each of the input data items is described in Section VIII of this report. The logic used for subroutine REED is not diagrammed.

D. Subroutine ADT

The flow diagram for subroutine ADT is shown in Figure 27. The annual average daily total flows are calculated for a major and secondary highway at the analysis site for each future year which may be included in the analysis. A test at the beginning of the routine determines if average daily totals for each future year have been supplied directly by the program user through input in subroutine REED.

E. Subroutine SIG

The purpose of subroutine SIG, a possible future addition to the model, is to determine whether "significant" accident savings are possible. The routine calculates SIGT, a measure of the potential for reducing accidents with countermeasures. The diagram of SIG, shown in Figure 28, suggests an approach that could be used to incorporate a test for significant savings in accident costs into the model.

F. Subroutine SIG0

Subroutine SIG0 is intended for use in conjunction with subroutine SIG. If the test for potential accident savings is made and found lacking, the program does not proceed. Instead the basis for termination is printed by subroutine SIG0. The output uses the same general format and headings as the output described in Section IX of this report. However, in SIG0, the main heading is TERMINATED ON LACK OF SIGNIFICANT SAVINGS. And, only EUAAC(1) and EUAAC(2) are printed.

G. Subroutine ALIFE

The flow diagram for subroutine ALIFE is shown in Figure 29. The routine calculates the applied life, LAF(KM), of each countermeasure, (KM), to be evaluated at the site analyzed. Prior to calculation each LAF(KM) is tested individually to determine if the program user has supplied the LAF(KM) in input. (If the user supplies LAF(KM), FCW(KM) must also be supplied in input.)

H. Subroutine FCAPW

The flow diagram for subroutine FCAPW is shown in Figure 30. The routine calculates the final capital worth FCW(KM) per capital item of each countermeasure, (KM), after LAF(KM) years of service at the site analyzed. Prior to calculation each FCW(KM) is individually tested to determine if the program user has supplied the FCW(KM) in input.

I. Subroutine EACC

Subroutine EACC is diagrammed in Figure 31. This routine calculates, for each requested countermeasure, the equivalent uniform annual capital cost, EUACC(KM), and the capital outlay, C0L(KM). These are the project costs (rather than unit costs) at the analysis site. The right-of-way costs, if any, are included.

J. Subroutine EFEAS

Subroutine EFEAS is diagrammed in Figure 32. For each countermeasure, KM, specified by the user, this routine establishes the period of analysis, IA, and calculates the benefit/cost ratios, BCR(KM), for economic feasibility. The routine prints these results in the economic feasibility output format presented in Section IX of this report.

K. Subroutine PFRM

Subroutine PFRM is diagrammed in Figure 33. This routine calculates the benefit/cost ratios, BCR(KM), for project formulation. The routine prints these results in the project formulation output format presented in Section IX of this report.

L. Subroutine B0C

Subroutine B0C is diagrammed in Figure 34. It is called in the economic feasibility stage by subroutine EFEAS and in the project formulation stage by subroutine PFRM. Subroutine B0C determines the benefit/cost ratios and other cost and benefit measures in both stages of the analysis.

M. Subroutine SEQ

Subroutine SEQ is called by subroutine PFRM at the beginning of the project formulation stage. This routine arranges the countermeasures that are economically feasible in order of increasing capital costs, so that the project formulation stage may proceed. The logic for subroutine SEQ is not diagrammed. The specifications for this subroutine follow:

Initial conditions when SEQ is called: Benefit/cost ratios, BCR(JJ), have been calculated in economic analyses (in subroutine EFEAS) for countermeasures identified by subscripts JJ, where the subscripts are JJ = KLST(J), J = 2, MLST.

It is known that NCEPT of the countermeasures provided benefit/cost ratios ≥ 1.0 and that NCEPT > 1.

Purpose of routine SEQ: Select the NCEPT countermeasures with BCR(JJ) ≥ 1.0 and sort them according to the countermeasure property EUACC(JJ), where EUACC(JJ) is the equivalent uniform annual capital cost for the countermeasure with subscript JJ.

Establish the list, ILST (J), J = 1, NCEPT, where the ILST (J) are the subscripts of the NCEPT qualifying countermeasures in the sequence of smallest EUACC( ) to largest EUACC( ) for J = 1 to NCEPT.

Note: The original sequence, KLST(J), and its limit, J = MLST, are saved for possible use in additional analyses (variations of same case) requested in input.

N. Subroutine COSTS(JJ)

Subroutine CØSTS(JJ) is diagrammed in Figure 35. This routine assembles the costs, exclusive of capital costs, for the analysis site with countermeasure JJ in the years 1 through IA. This routine employs subroutines SETCST, CALCST, YRMØ, YRAC, and YRUC.

O. Subroutine SETCST

Subroutine SETCST is diagrammed in Figure 36. The routine is called in subroutine CØSTS(JJ) prior to the loop which calculates year-by-year costs. It sets up initial values and coefficients for the loop and also calculates applicable accident and user costs for the zeroth year. Subroutine SETCST calls subroutines SKIDI, CØRRT, GREDU, DTØUR and DTAØJ. When the routine is exited, the accident rate in the zeroth year has been adjusted for the effect of geometric and surface modification countermeasures. In addition, coefficients have been defined to describe subsequent changes in skid number due to traffic wear and subsequent changes in accident rate due to changes in ADT and skid number. Finally, the routine defines coefficients for maintenance and operating costs, for future user costs due to countermeasure construction and calculates ACØST, the average cost per accident for the severity distribution after countermeasure implementation.

P. Subroutine SKIDI

Subroutine SKIDI is diagrammed in Figure 37. The purpose of this routine, which is called by subroutine SETCST, is to determine coefficients for the calculation of skid number in future years. The routine determines values for variables SNYØ, SNØ, CS, SDF, KW, KSYR and an initial value for variable CT.

Q. Subroutine C0RRT

Subroutine C0RRT is diagrammed in Figure 35. The primary purpose of the routine is to calculate GC0R, a correction factor applied to the percent accident reduction for geometric and traffic control countermeasures. However, the routine also calculates SLGTH, a psuedo-length of analysis site for spot locations, and sets values for B0, B1 and A1 used in the subsequent calculation of the effect of changes in skid number on accident rate.

R. Subroutine GREDU

Subroutine GREDU is diagrammed in Figure 39. This routine calculates ALFI and ALPD0, the number of accidents remaining after implementation of geometric and traffic control countermeasures for fatal-and-injury and property-damage-only accidents, respectively.

S. Subroutine DT0UR

Subroutine DT0UR is diagrammed in Figure 40. The routine calculates AT0UR, the fractional increase in yearly accidents due to countermeasure construction, and YUC, the added user costs due to construction delays and excess fuel consumption. This routine determines all user costs currently incorporated in the model.

T. Subroutine SNADJ

Subroutine SNADJ is diagrammed in Figure 41. This routine is used in a year-by-year loop to correct the accident rate for the previous year to the appropriate accident rate for the current year accounting only for changes in skid number.

U. Subroutine CALCST

Subroutine CALCST is diagrammed in Figure 42. For each year of the analysis period after the zeroth year, this subroutine updates the skid number and adjusts the accident rate for changes in ADT and skid number by calling subroutines SKIDC, DTADJ and SNADJ. In addition, the routine calls subroutine DT0UR, if necessary, to calculate user costs for countermeasure construction in any year after the zeroth year.

V. Subroutine SKIDC

Subroutine SKIDC is diagrammed in Figure 43. This routine accumulates CT, the total traffic exposure since installation of a countermeasure. The routine also (1) updates the skid number for each year, (2) decrements KSYR, the remaining life of the surface course, and (3) sets KUC = 1, where appropriate, to indicate that construction will occur in the year being processed and that subroutine DT0UR must be called.

W. Subroutine DTADJ

Subroutine DTADJ is diagrammed in Figure 44. This routine calculates DTJST, a factor that is used to adjust the previous year accident rate to the current rate accounting only for the effect of ADT.

X. Subroutine ACC0ST

Subroutine ACC0ST is diagrammed in Figure 45. This routine calculates CTFI and CTPD0, the average cost of fatal-and-injury and property-damage-only accidents, respectively, for the area type and highway type in which the analysis site is located.

Y. Subroutine YRM0

Subroutine YRM0 is diagrammed in Figure 46. This routine calculates YM0, the maintenance and operating costs for the year being processed.

Z. Subroutine YRAC

Subroutine YRAC is diagrammed in Figure 47. This routine calculates YRAC, the accident costs for the year being processed.

AA. Subroutine YRUC

Subroutine YRUC is used to calculate user costs other than those due to construction delays and excess fuel consumption. Because such additional user costs are not included in the current version of the model, YRUC is currently a dummy subroutine. It provides an appropriate place in the model for consideration of other user costs that might be added at a later date.

BB. Subroutine DC0STS

Subroutine DC0STS is diagrammed in Figure 48. This routine calculates the equivalent uniform annual user costs associated with countermeasure construction. If the duration of construction activity (TDUR) is zero, the user costs associated with construction are set to zero. Subroutine DT0UR is called in Subroutine DC0STS to calculate the actual user costs due to construction and excess fuel consumption. The program then returns to Subroutine DC0STS where the user costs calculated in Subroutine DTOUR are converted to an equivalent uniform annual basis.

C DURING BENEFIT-COST PROGRAM EXECUTION ALL SYSTEM FILES ARE AVAILABLE IN SEQUENTIAL FORM

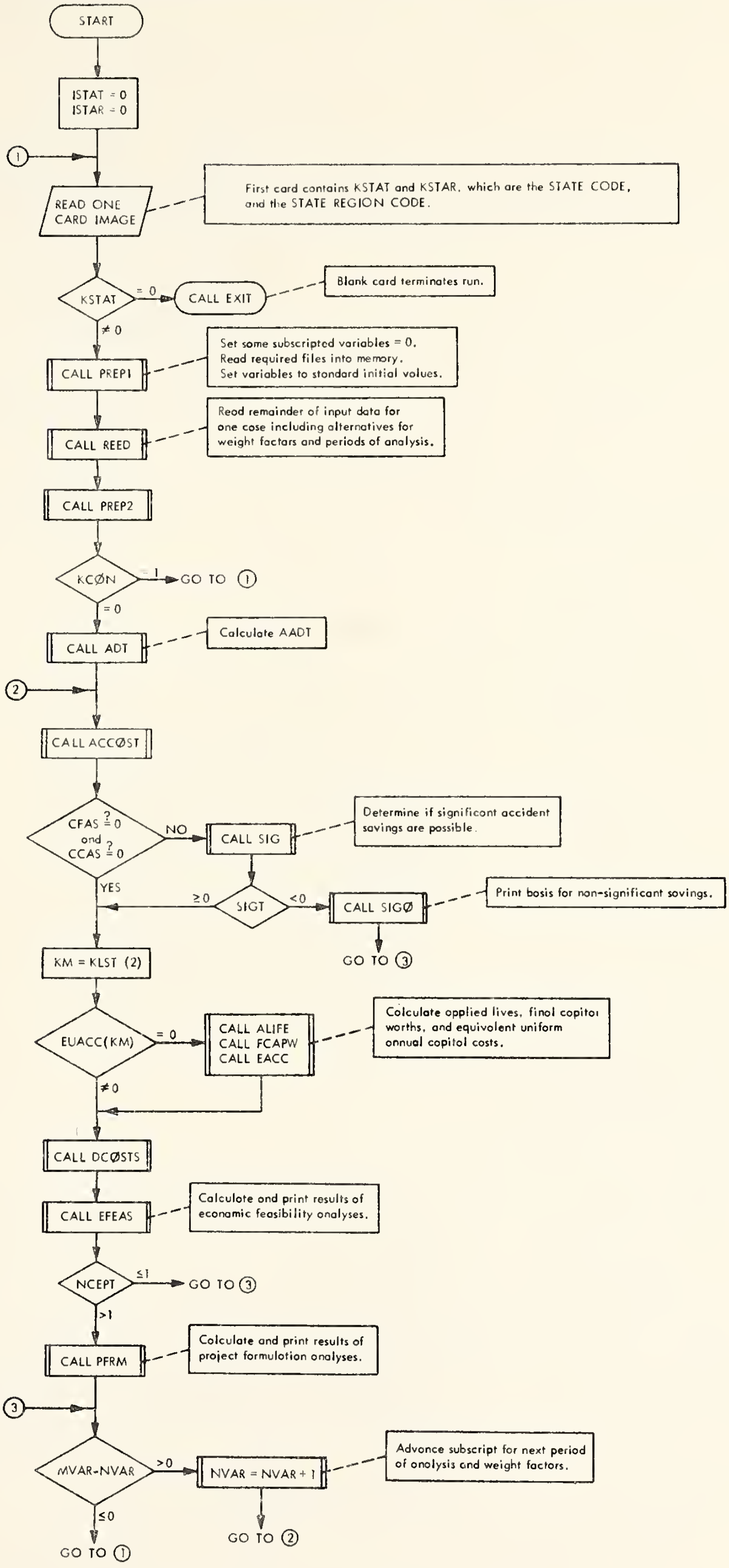


Figure 24 - Benefit-Cost Flow Diagram

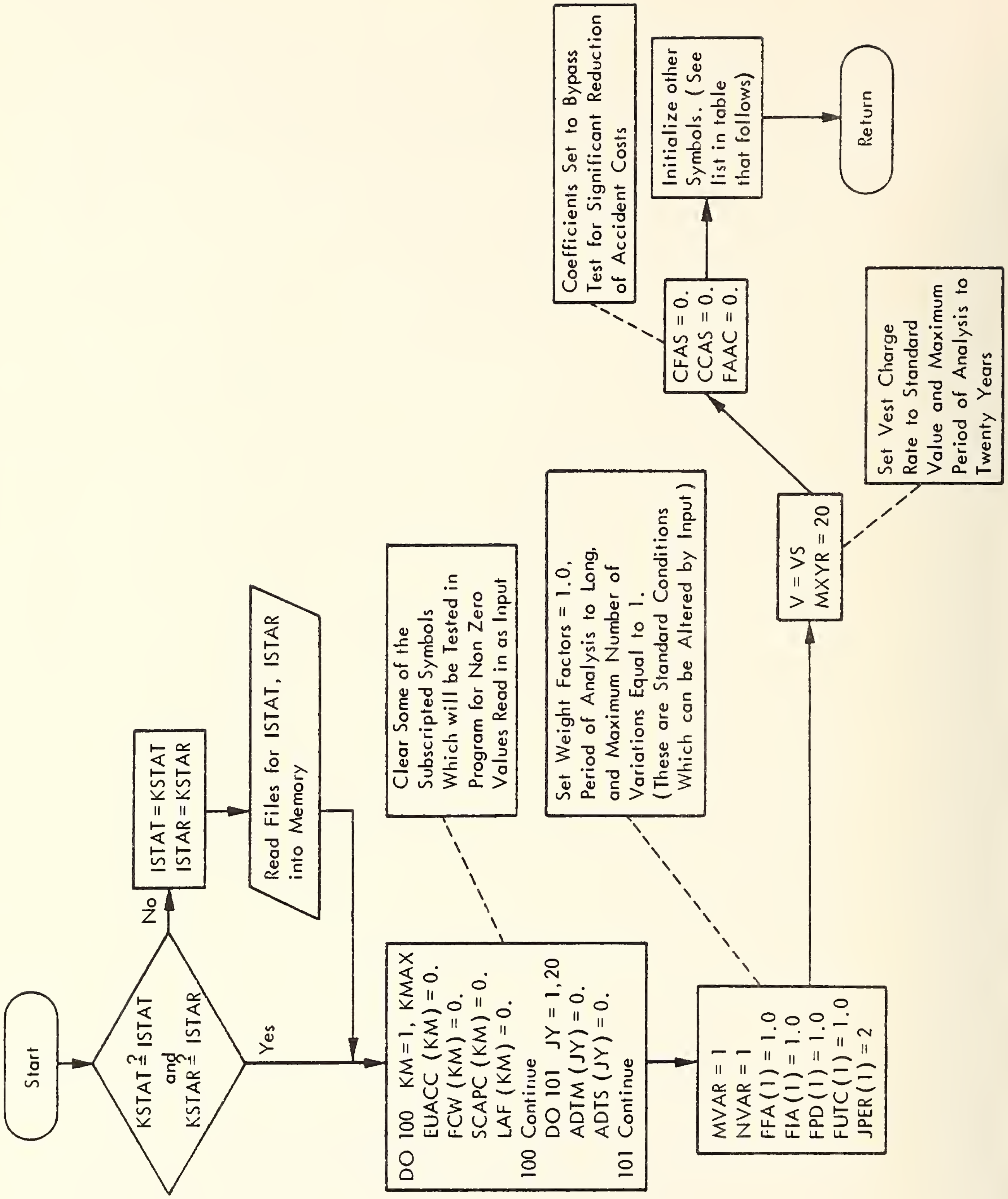


Figure 25 - Subroutine PREP1 Flow Diagram

TABLE 26

ADDITIONAL INITIAL VALUES TO BE SET IN SUBROUTINE PREP1

Set MLST = 1

Set the following equal to zero:

Non-Subscripted Variables

ANIT
AØTH
APDØ
APR
APREC
ARA
ARE
ASS
AWET
IRS
KWS
SNYØ
TIM
TIS
TLGH
TMGC
TSGC
TSGL
APED
SNYØ
BPNYØ
AMDYØ

Subscripted Variables

KCSCD(KM) KM = 1, KMAX
KZØW(KM) KM = 1, KMAX
PRALL(KM) KM = 1, KMAX
PRDAY(KM) KM = 1, KMAX
PRDRY(KM) KM = 1, KMAX
PRFI(KM) KM = 1, KMAX
PRFØ(KM) KM = 1, KMAX
PRHØ(KM) KM = 1, KMAX
PRLT(KM) KM = 1, KMAX
PRNIT(KM) KM = 1, KMAX
PRØTH(KM) KM = 1, KMAX
PRPDØ(KM) KM = 1, KMAX
PRPED(KM) KM = 1, KMAX
PRPR(KM) KM = 1, KMAX
PRRA(KM) KM = 1, KMAX
PRRE(KM) KM = 1, KMAX
PRSS(KM) KM = 1, KMAX
PRWET(KM) KM = 1, KMAX
SCMAØ(KM) KM = 1, KMAX
SMAØM(KM) KM = 1, KMAX
SSMAØ(KM) KM = 1, KMAX
TDUR(KM) KM = 1, KMAX
UN(KM) KM = 1, KMAX
ZLGH(KM) KM = 1, KMAX

Subroutine PREP2

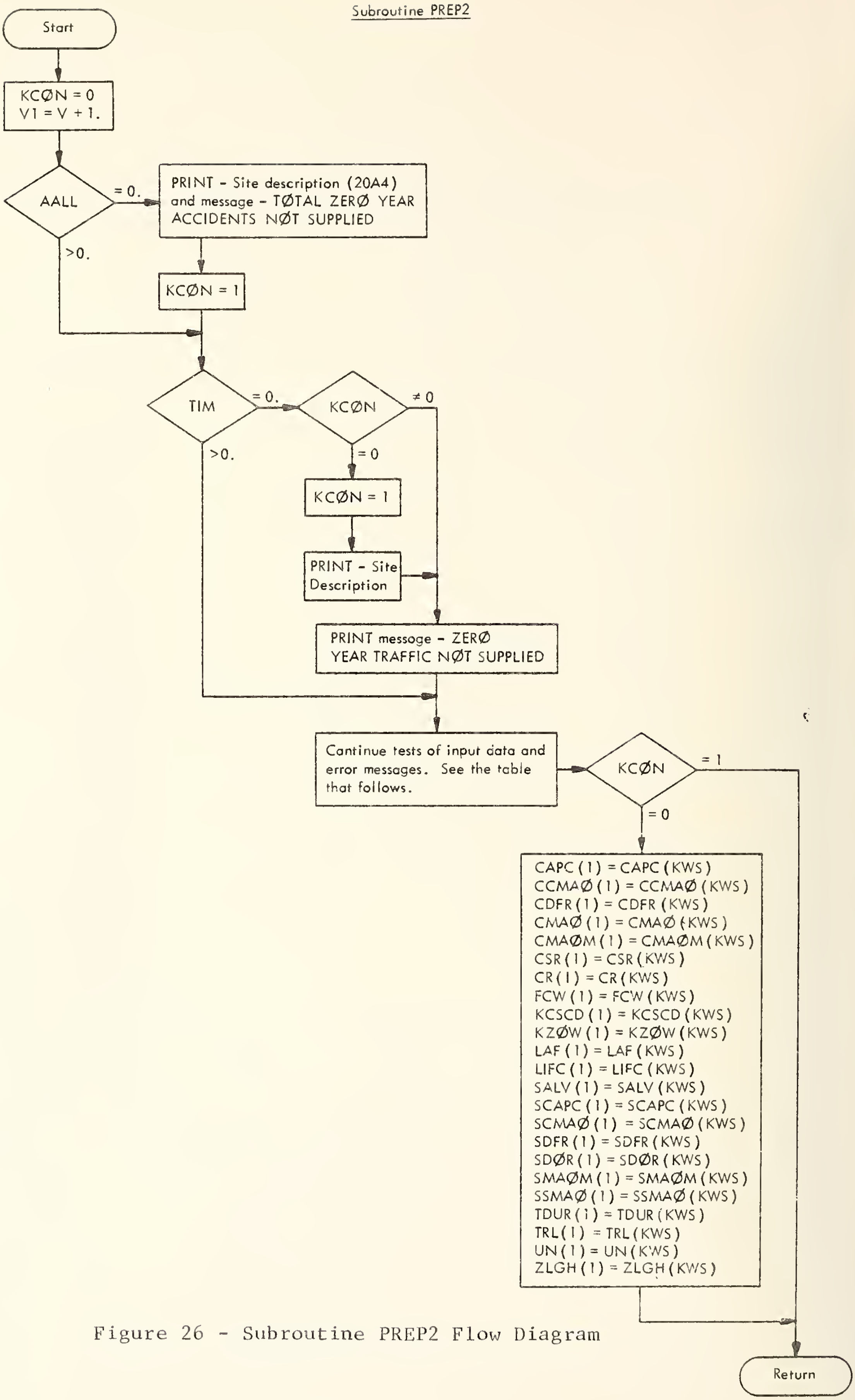


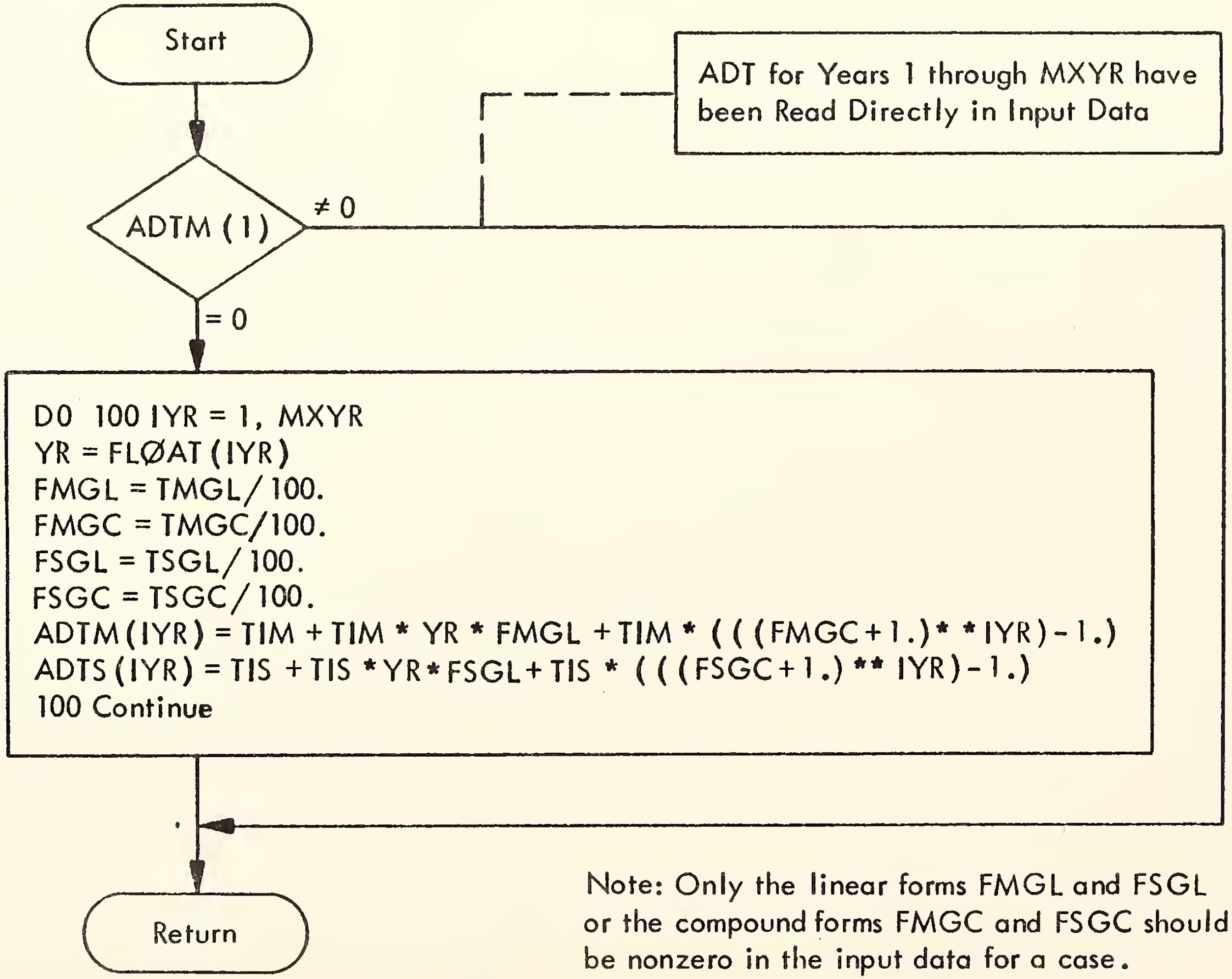
Figure 26 - Subroutine PREP2 Flow Diagram

TABLE 27

TESTS AND MESSAGES FOR SUBROUTINE PREP2

Test[1]	Message if Passed
AALL = 0	OVERALL ACCIDENTS FOR ZERO YEAR NOT SUPPLIED
TIM = 0	ADT FOR ZERO YEAR NOT SUPPLIED
FWET = 0	FRACTION TIME WET NOT SUPPLIED
IATYP = 0 or IHTYP = 0 or ISITE = 0	AREA, HIGHWAY, OR SITE TYPE NOT SUPPLIED
KWS = 0	AS IS OR AS PLANNED SURFACE SUBSCRIPT NOT SUPPLIED
LIFF = 0	REMAINING LIFE OF FACILITY NOT SUPPLIED
LIFRS = 0 or LIFRB = 0	YEARS UNTIL RESURFACE OR YEARS UNTIL REBUILD NOT SUPPLIED
TLGH = 0	LENGTH OF SITE NOT SUPPLIED
MLST = 0	COUNTERMEASURES FOR ANALYSIS NOT SUPPLIED

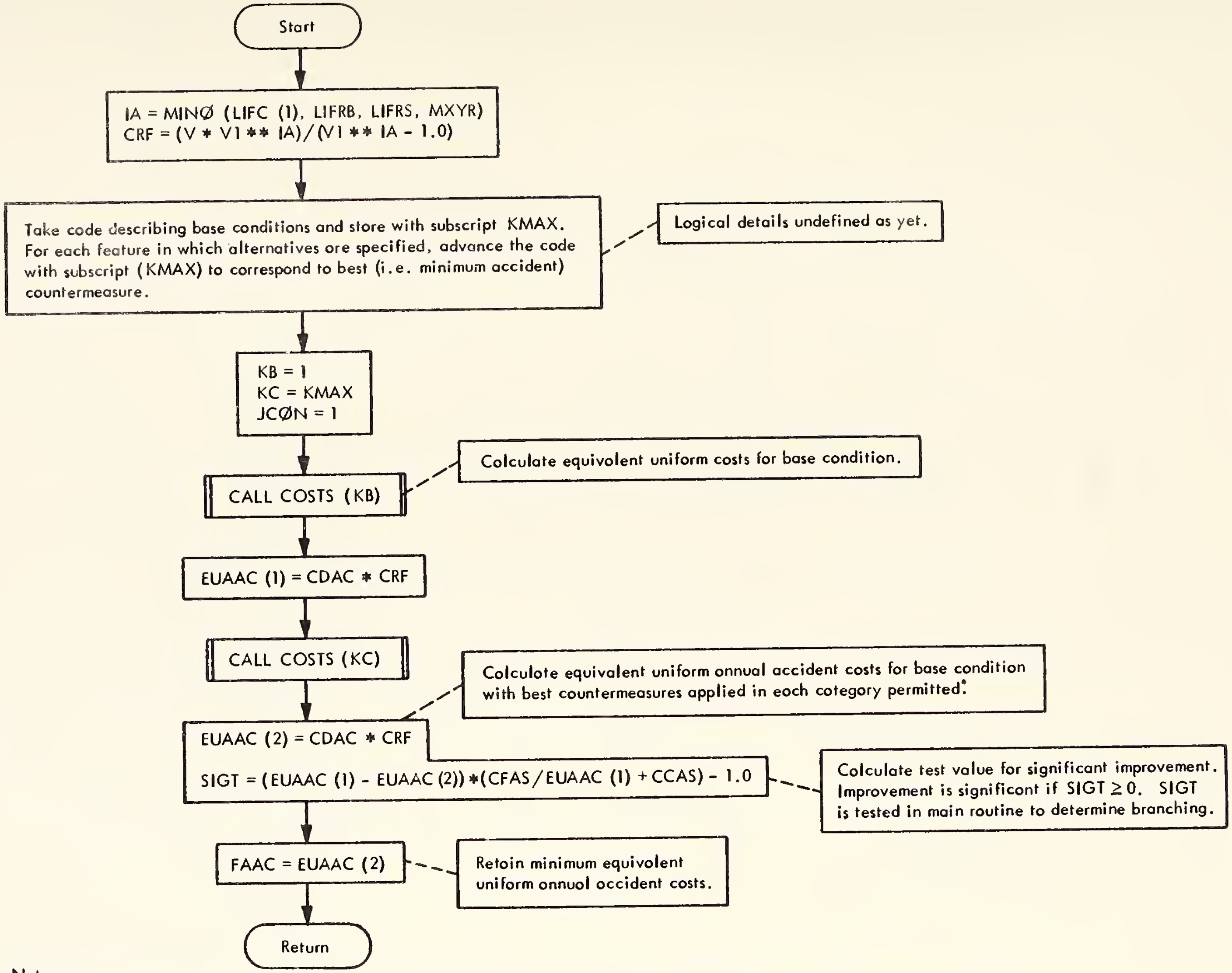
1/ When any listed test is passed KCØN should be tested. And, if KCØN = 0 it should be set KCØN = 1 and the site description (20A4) printed prior to the message in the table.



```
DO  100 IYR = 1, MXYR
YR = FLØAT (IYR)
FMGL = TMGL/ 100.
FMGC = TMGC/100.
FSGL = TSGL/ 100.
FSGC = TSGC/ 100.
ADTM(IYR) = TIM + TIM * YR * FMGL + TIM * ( ( (FMGC+1.)* *IYR)-1.)
ADTS(IYR) = TIS + TIS *YR*FSGL+ TIS * ( ( (FSGC+1.) ** IYR)-1.)
100 Continue
```

Note: Only the linear forms FMGL and FSGL or the compound forms FMGC and FSGC should be nonzero in the input data for a case.

Figure 27 - Subroutine ADT Flow Diagram



Notes:
SIGT is formed as CFAS * (fraction of accident costs eliminated) + CCAS * (annual dollars of accident costs eliminated) - 1.0.
Factors CFAS and CCAS are part of input.
Factors CFAS and CCAS are tested in the main program prior to calling this routine. If both = 0., main program branches around this routine.
This routine forms SIGT which has a value > 0 if a significant reduction in accident costs can be obtained.

Figure 28 - Subroutine SIG Flow Diagram

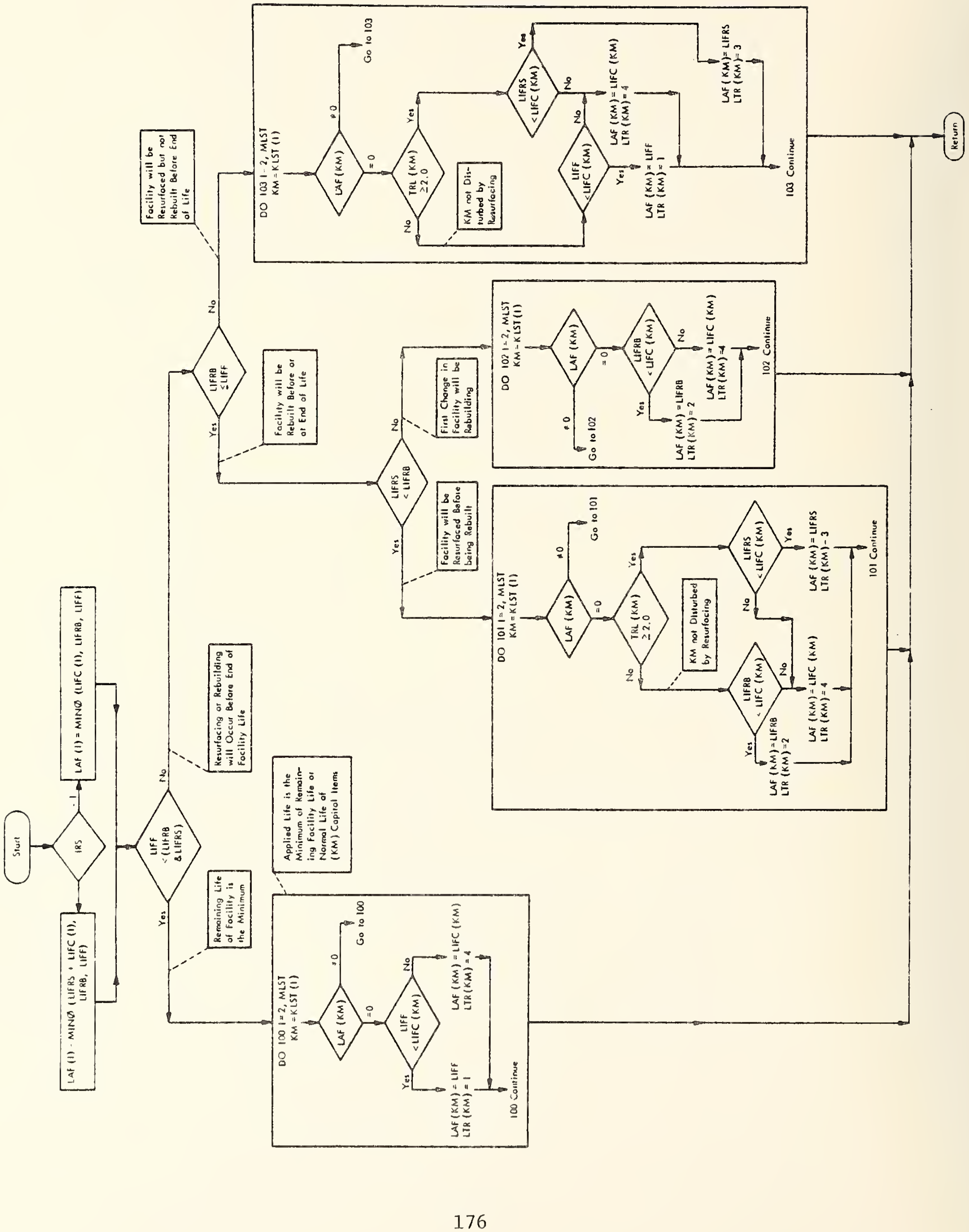


Figure 29 - Subroutine ALIFE Flow Diagram

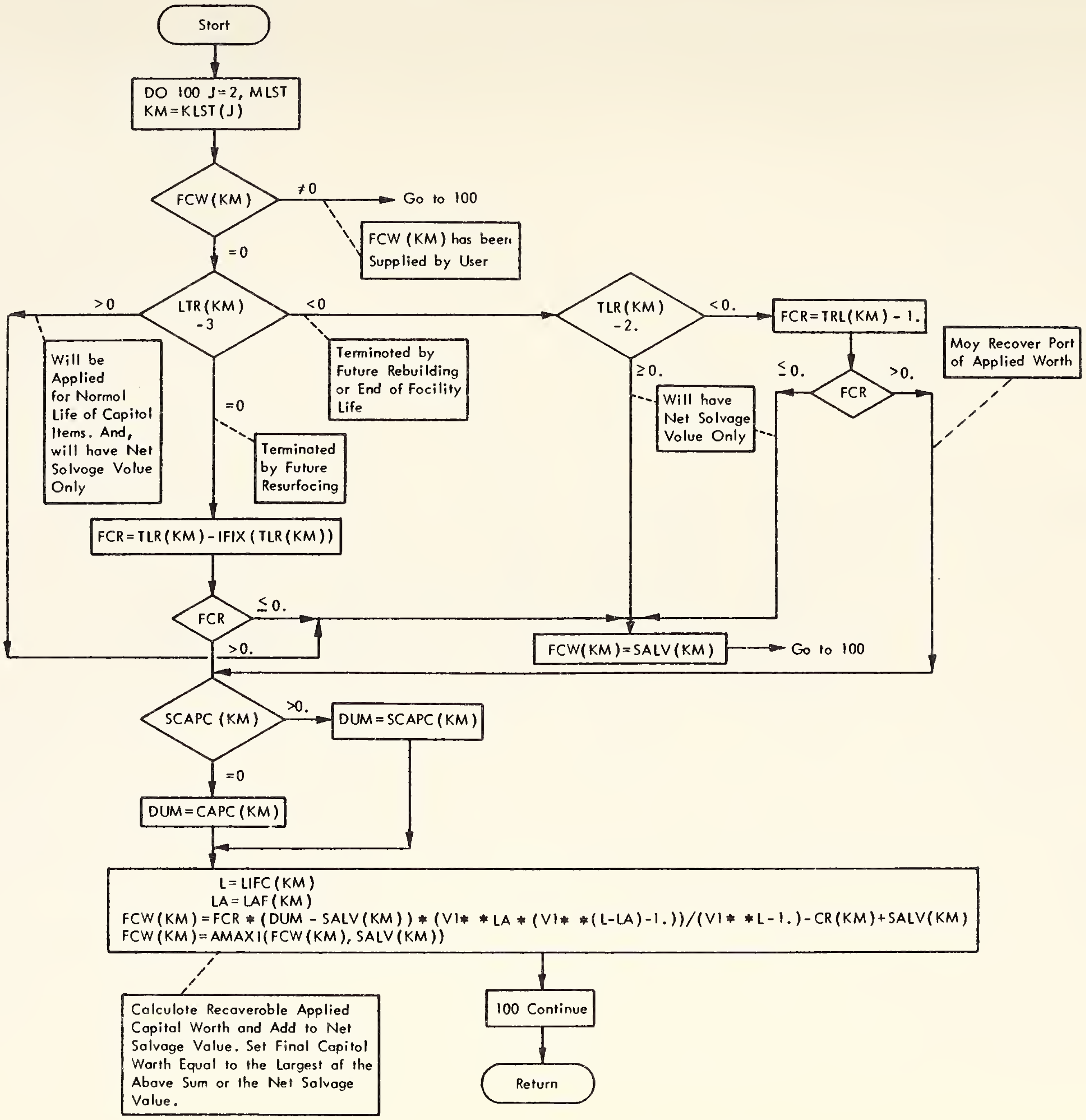


Figure 30 - Subroutine FCAPW Flow Diagram

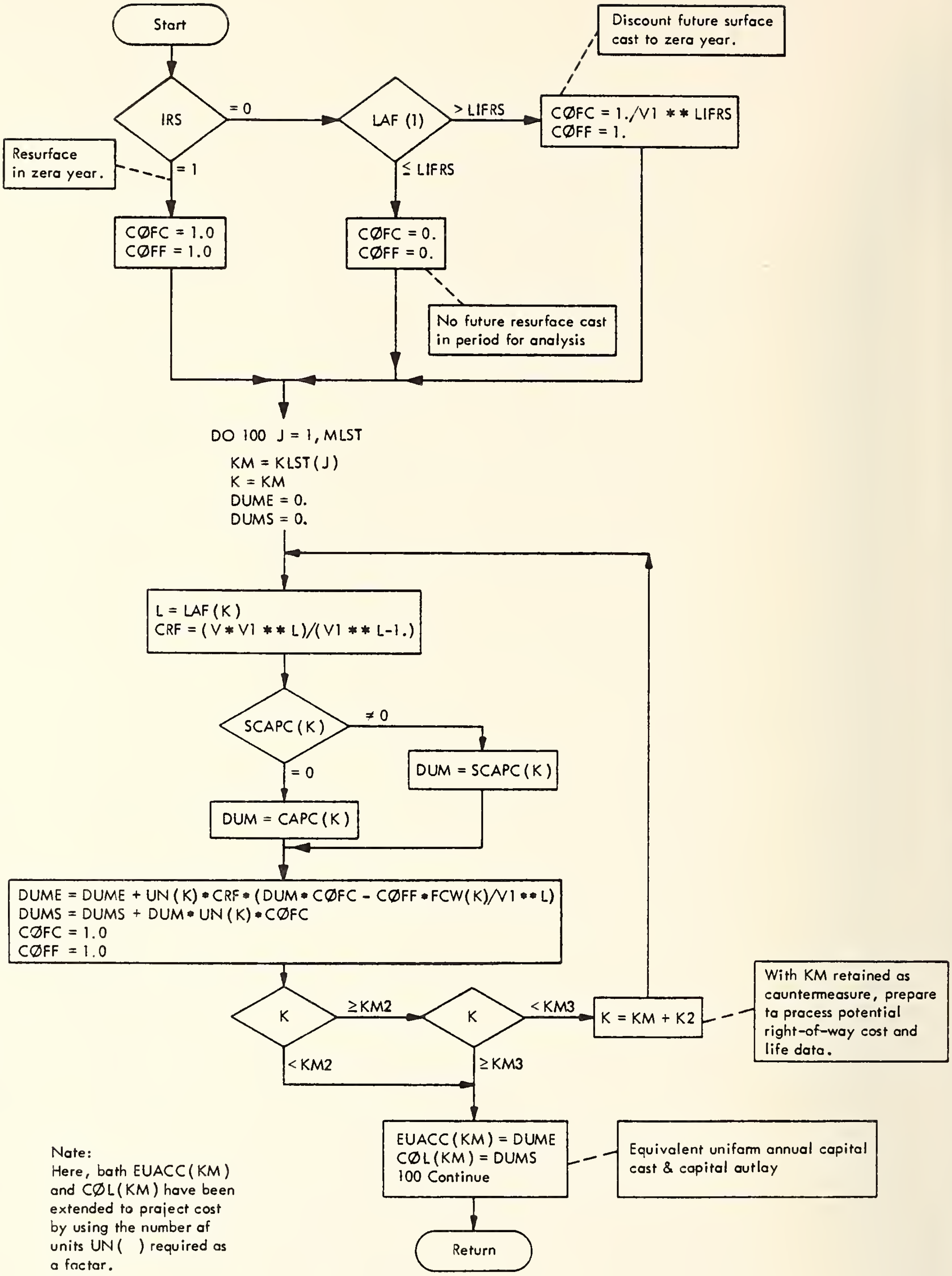


Figure 31 - Subroutine EACC Flow Diagram

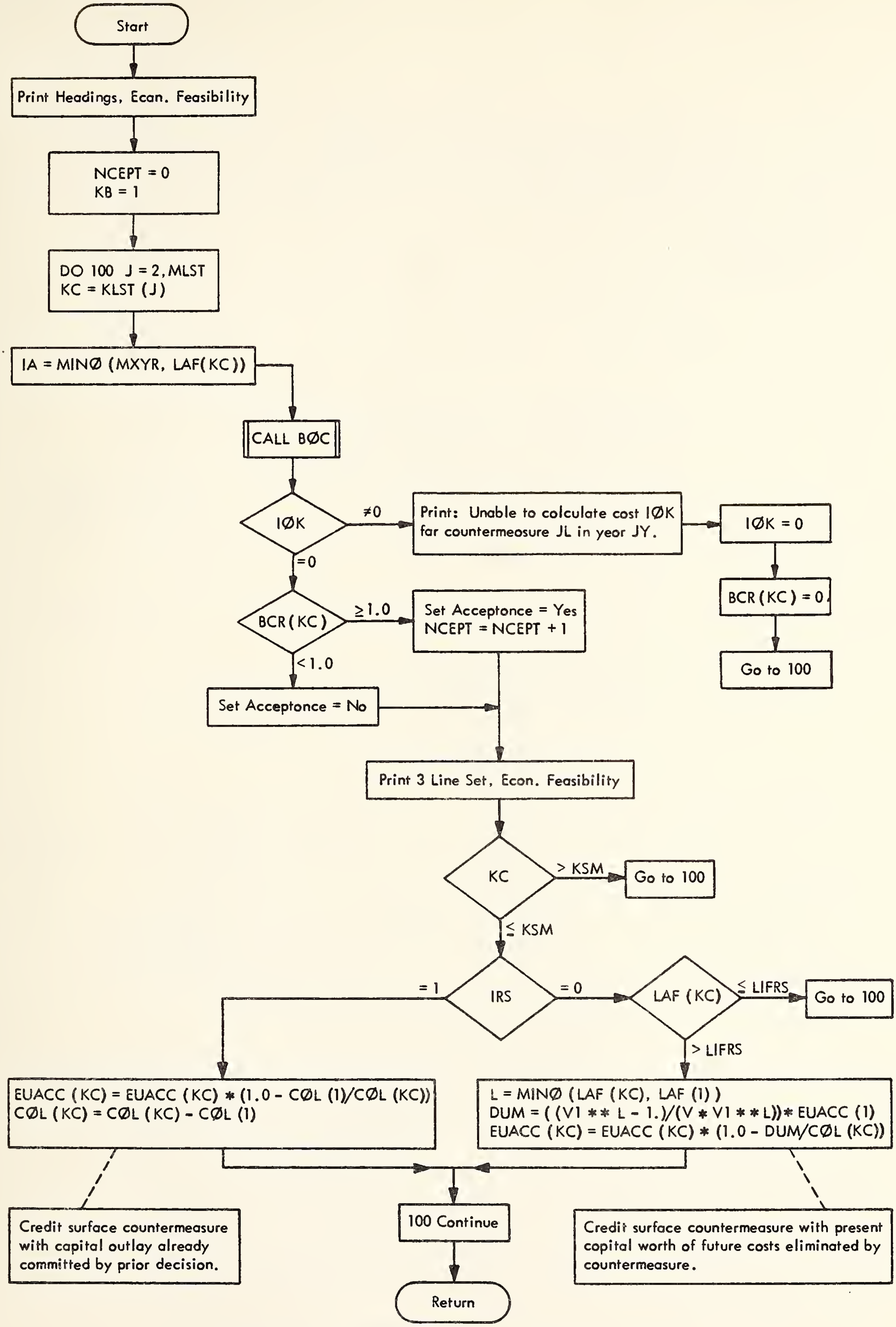


Figure 32 - Subroutine EFEAS Flow Diagram

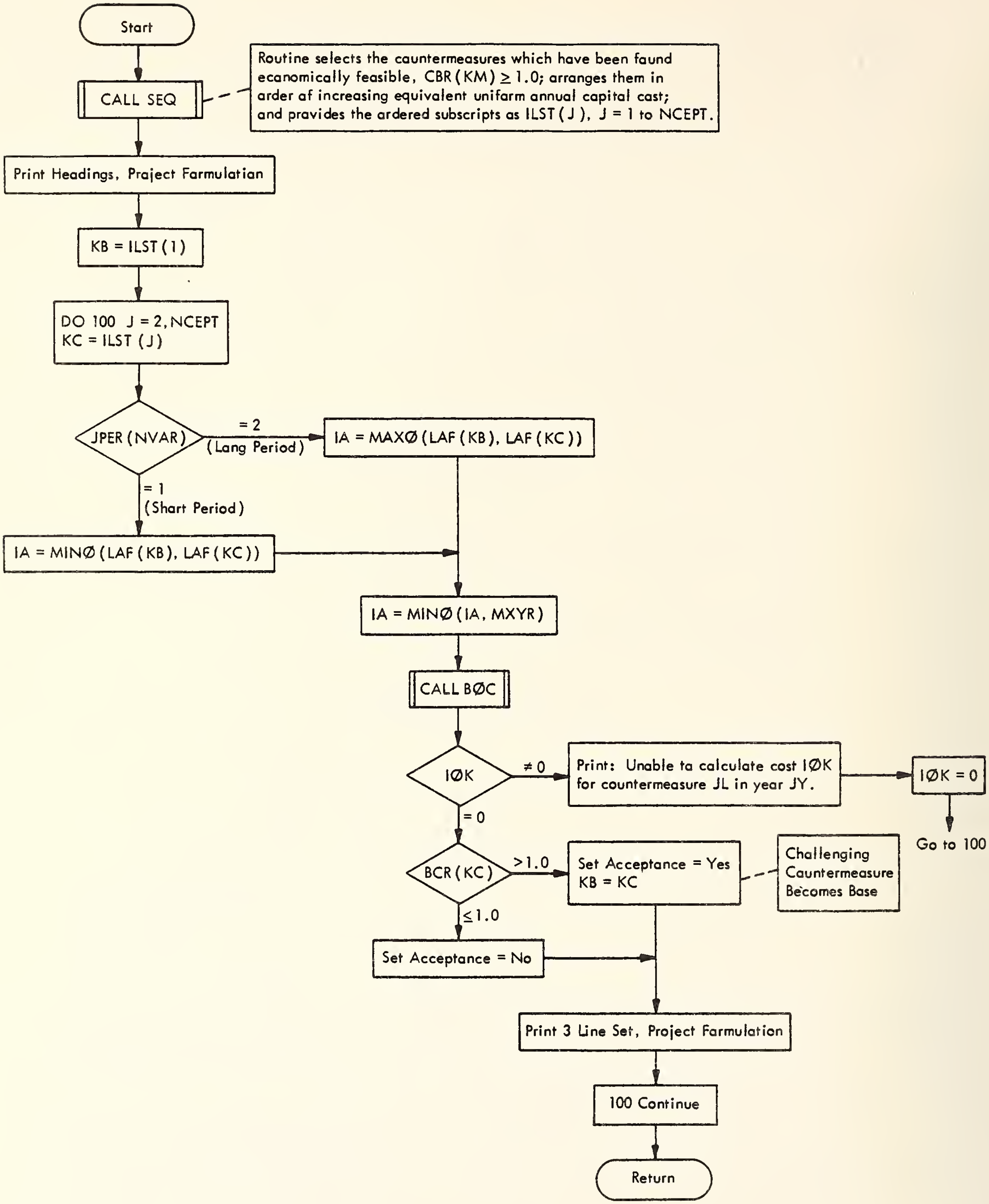


Figure 33 - Subroutine PFRM Flow Diagram

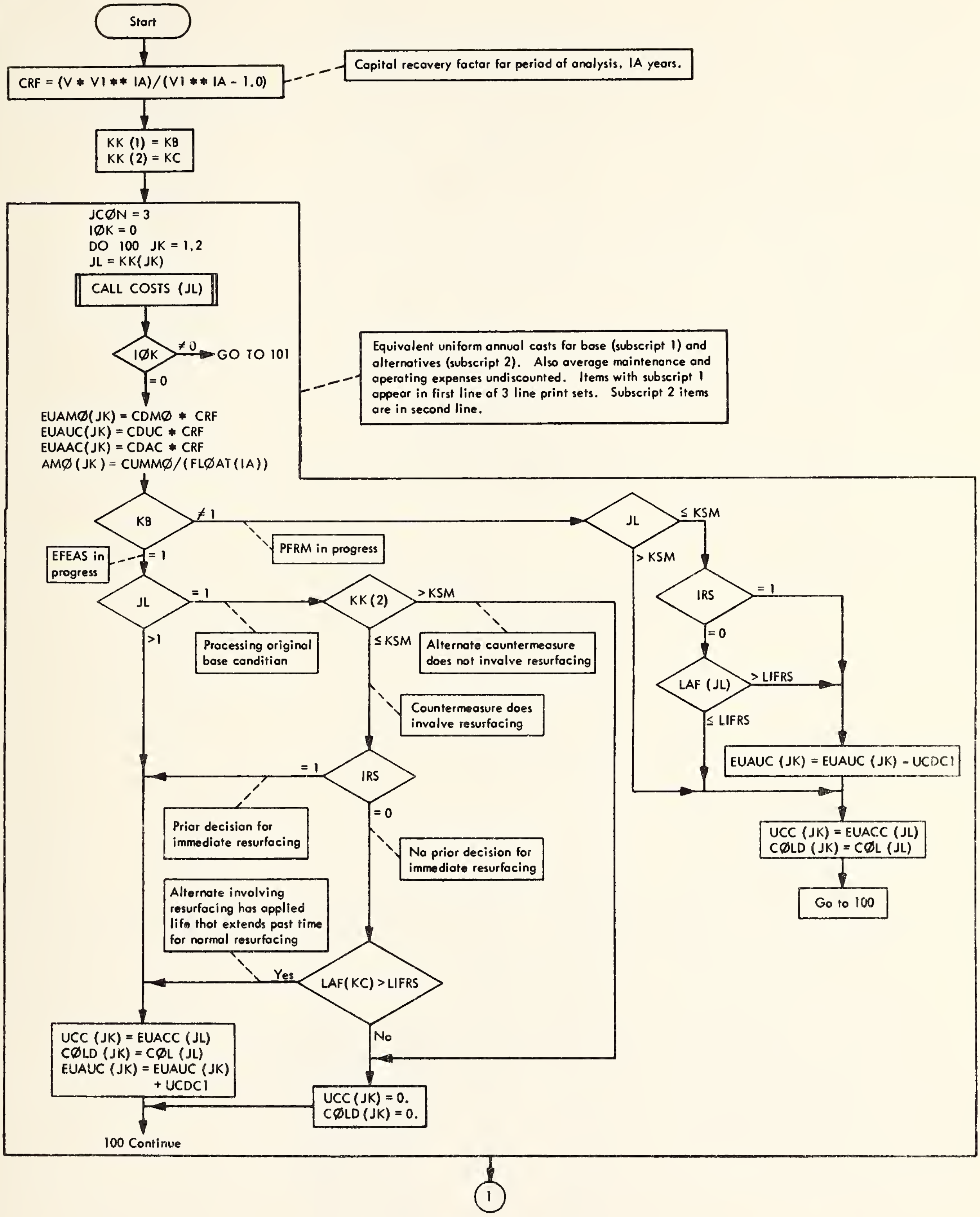
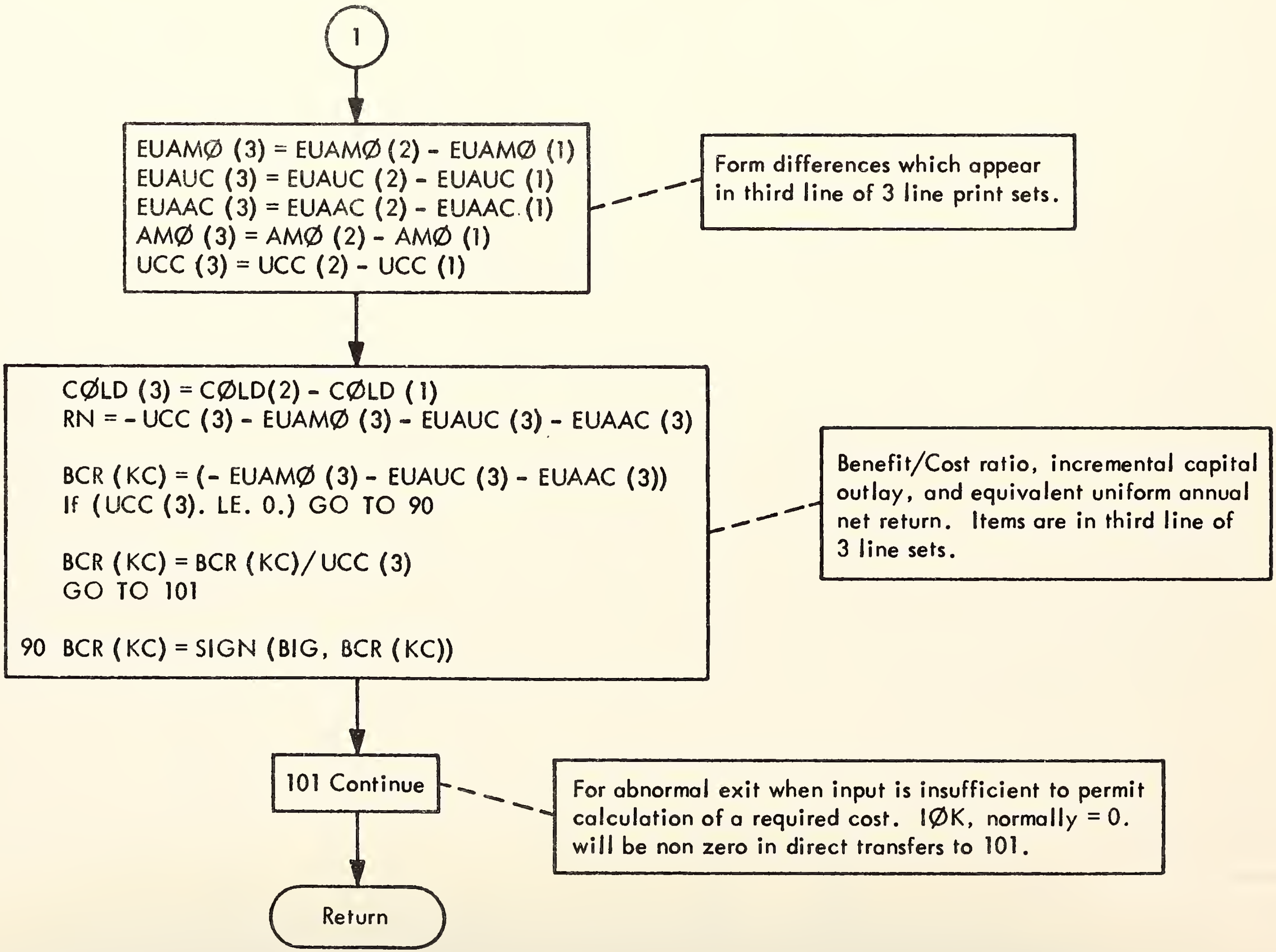


Figure 34 - Subroutine BOC Flow Diagram



```
EUAMØ (3) = EUAMØ (2) - EUAMØ (1)
EUAUC (3) = EUAUC (2) - EUAUC (1)
EUAAC (3) = EUAAC (2) - EUAAC (1)
AMØ (3) = AMØ (2) - AMØ (1)
UCC (3) = UCC (2) - UCC (1)
```

Form differences which appear in third line of 3 line print sets.

```
   CØLD (3) = CØLD(2) - CØLD (1)
   RN = - UCC (3) - EUAMØ (3) - EUAUC (3) - EUAAC (3)

   BCR (KC) = (- EUAMØ (3) - EUAUC (3) - EUAAC (3))
   If (UCC (3). LE. 0.) GO TO 90

   BCR (KC) = BCR (KC)/UCC (3)
   GO TO 101

90 BCR (KC) = SIGN (BIG, BCR (KC))
```

Benefit/Cost ratio, incremental capital outlay, and equivalent uniform annual net return. Items are in third line of 3 line sets.

```
101 Continue
```

For abnormal exit when input is insufficient to permit calculation of a required cost. IØK, normally = 0. will be non zero in direct transfers to 101.

Figure 34 (concluded)

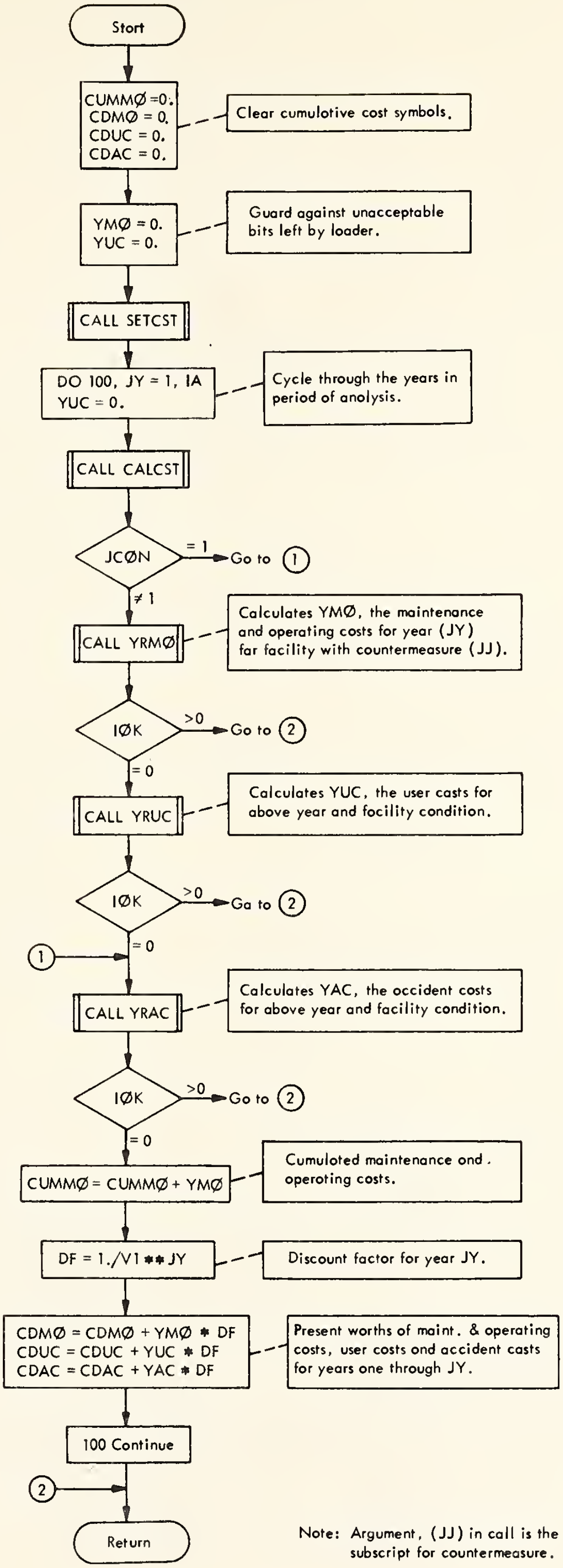
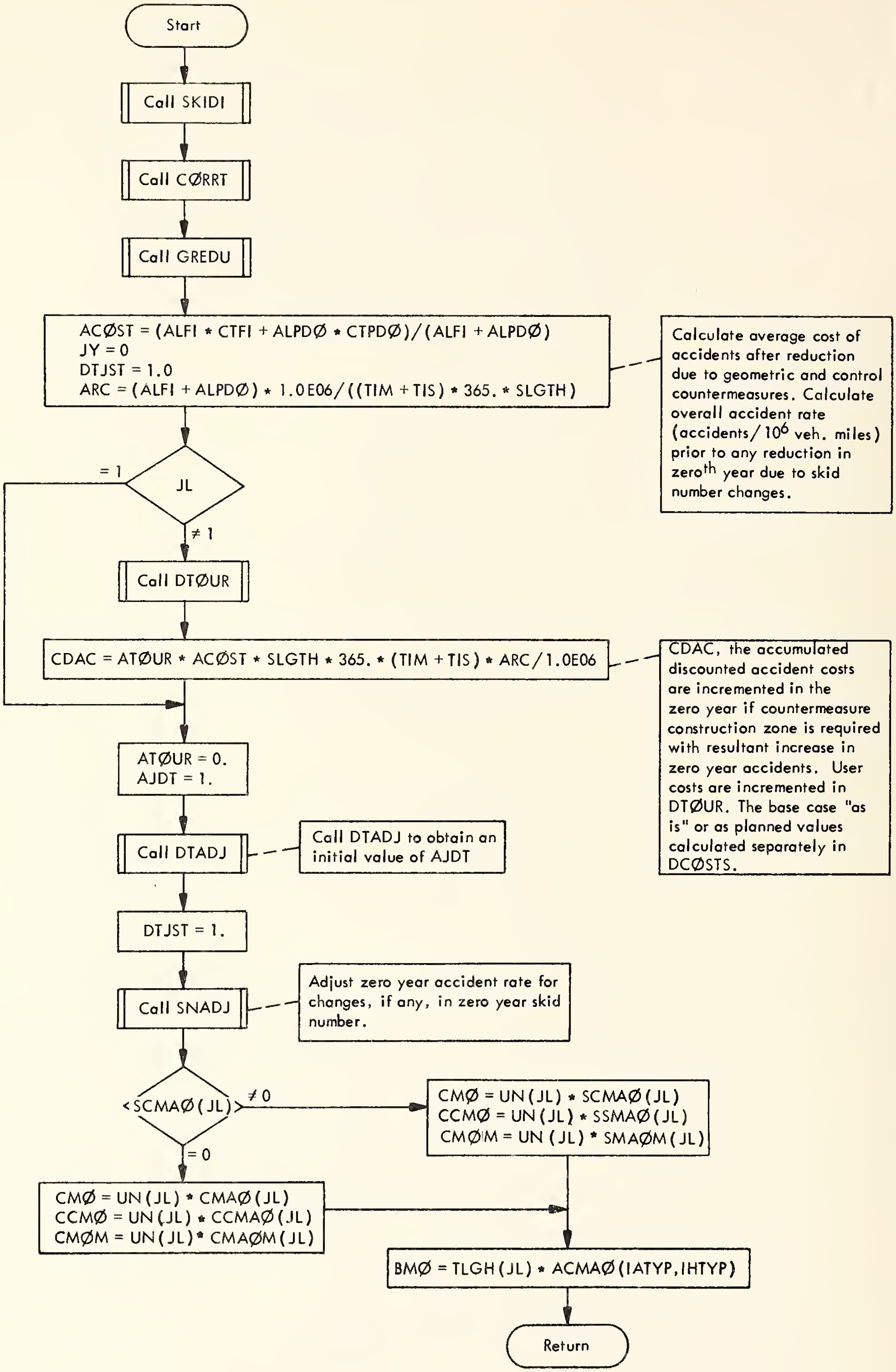


Figure 35 - Subroutine CØSTS(JJ) Flow Diagram

Subroutine SETCST



Calculate average cost of accidents after reduction due to geometric and control countermeasures. Calculate overall accident rate (accidents/10^6 veh. miles) prior to any reduction in zero^th year due to skid number changes.

CDAC, the accumulated discounted accident costs are incremented in the zero year if countermeasure construction zone is required with resultant increase in zero year accidents. User costs are incremented in DTØUR. The base case "as is" or as planned values calculated separately in DCØSTS.

Call DTADJ to obtain an initial value of AJDT

Adjust zero year accident rate for changes, if any, in zero year skid number.

Figure 36 - Subroutine SETCST Flow Diagram

Subroutine SKIDI
(Initiate Skid Number Calculations)

SNTEX (XBPN, XMD) = (1.38 * XBPN - 31.)/EXP (1.64/XMD ** .47)

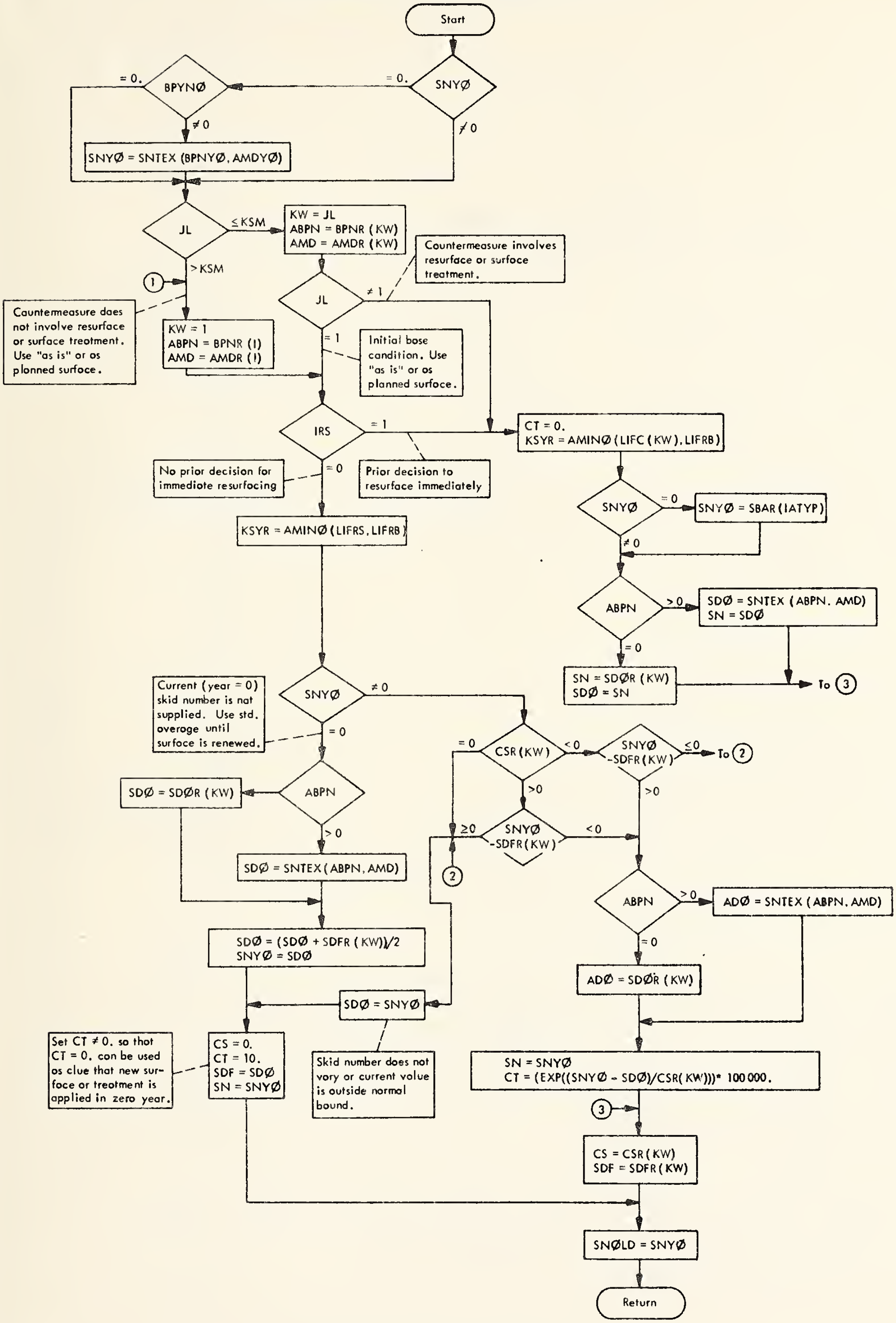


Figure 37 - Subroutine SKIDI Flow Diagram

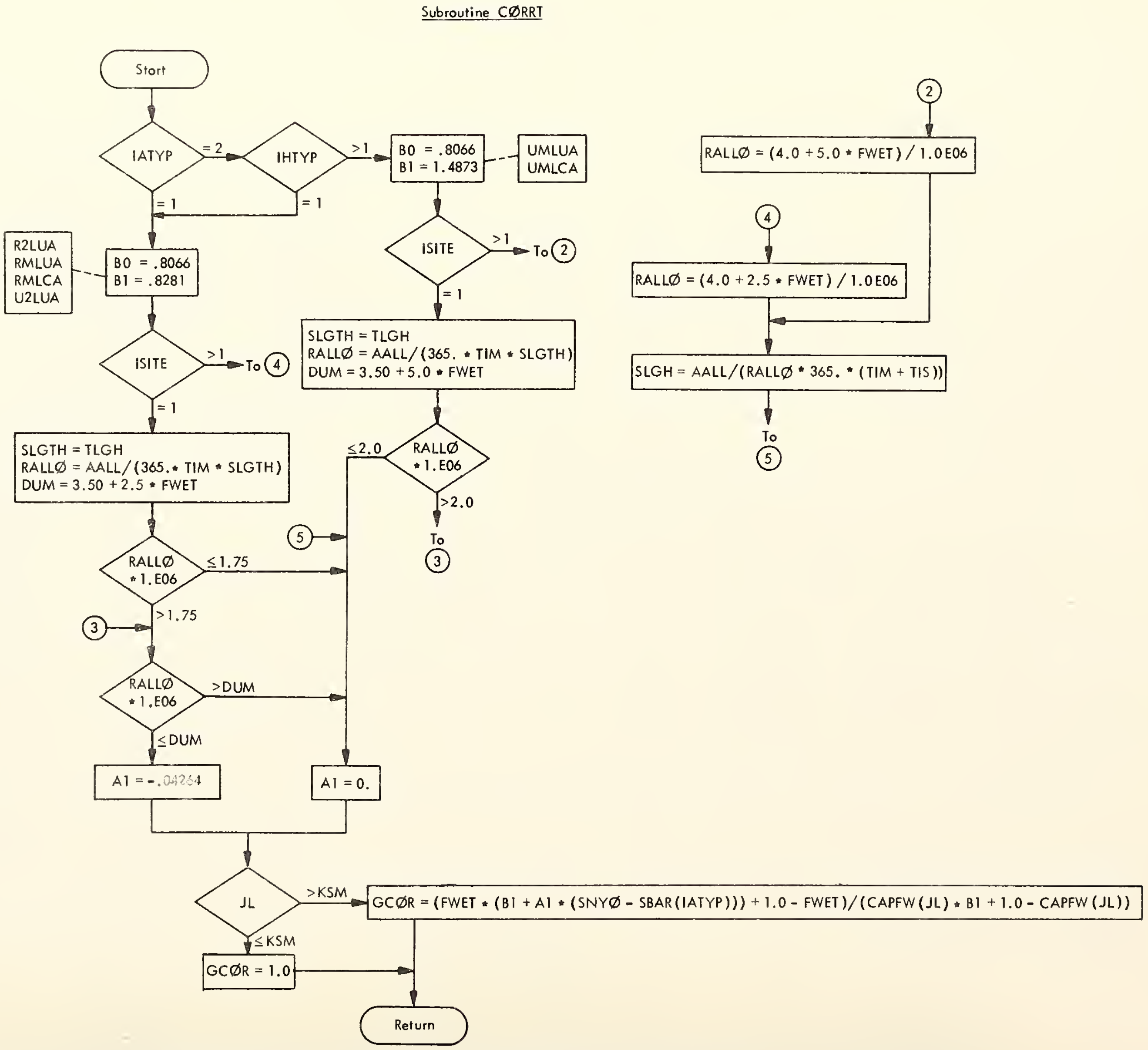


Figure 38 - Subroutine CØRRT Flow Diagram

Subroutine GREDU

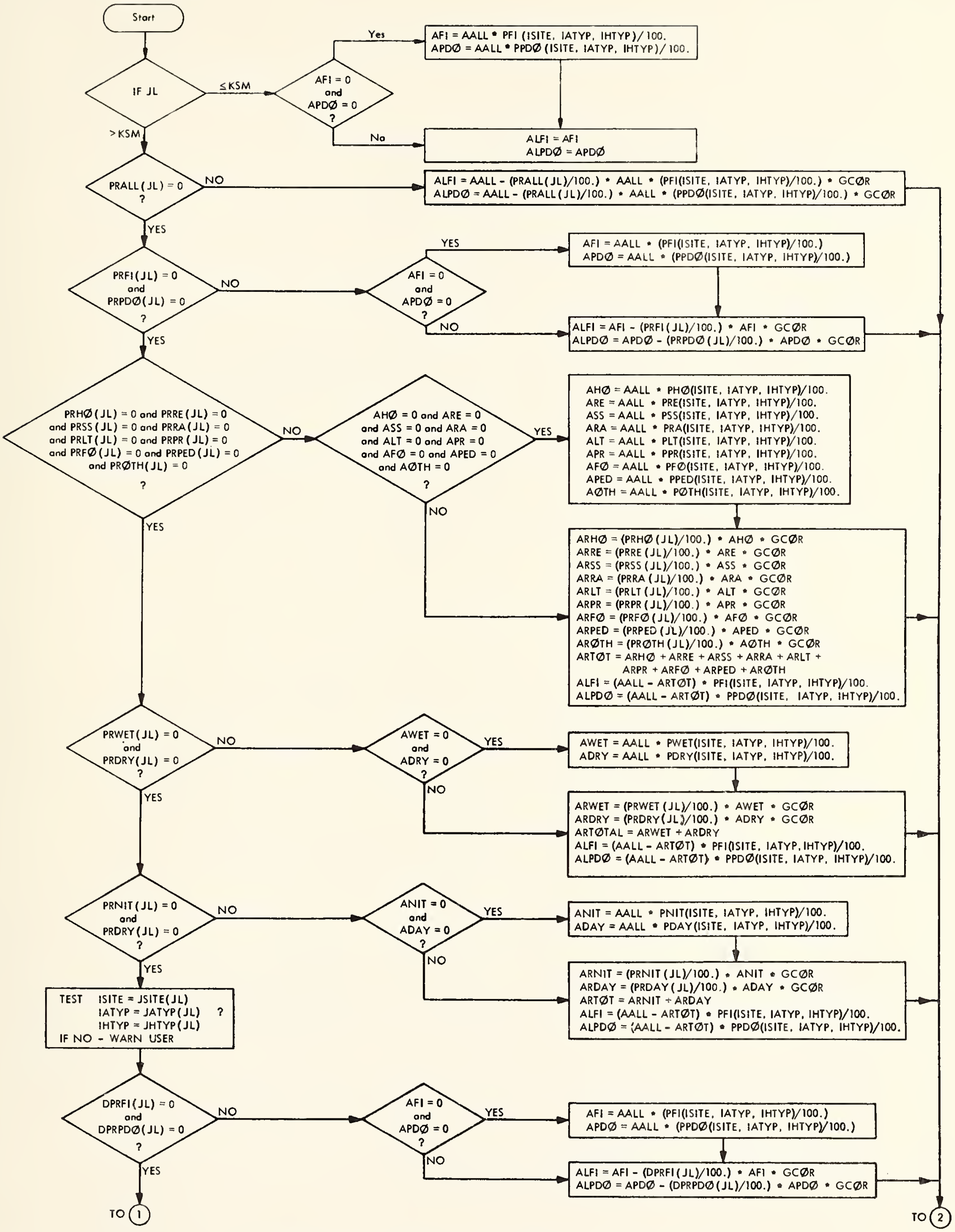


Figure 39 - Subroutine GREDU Flow Diagram

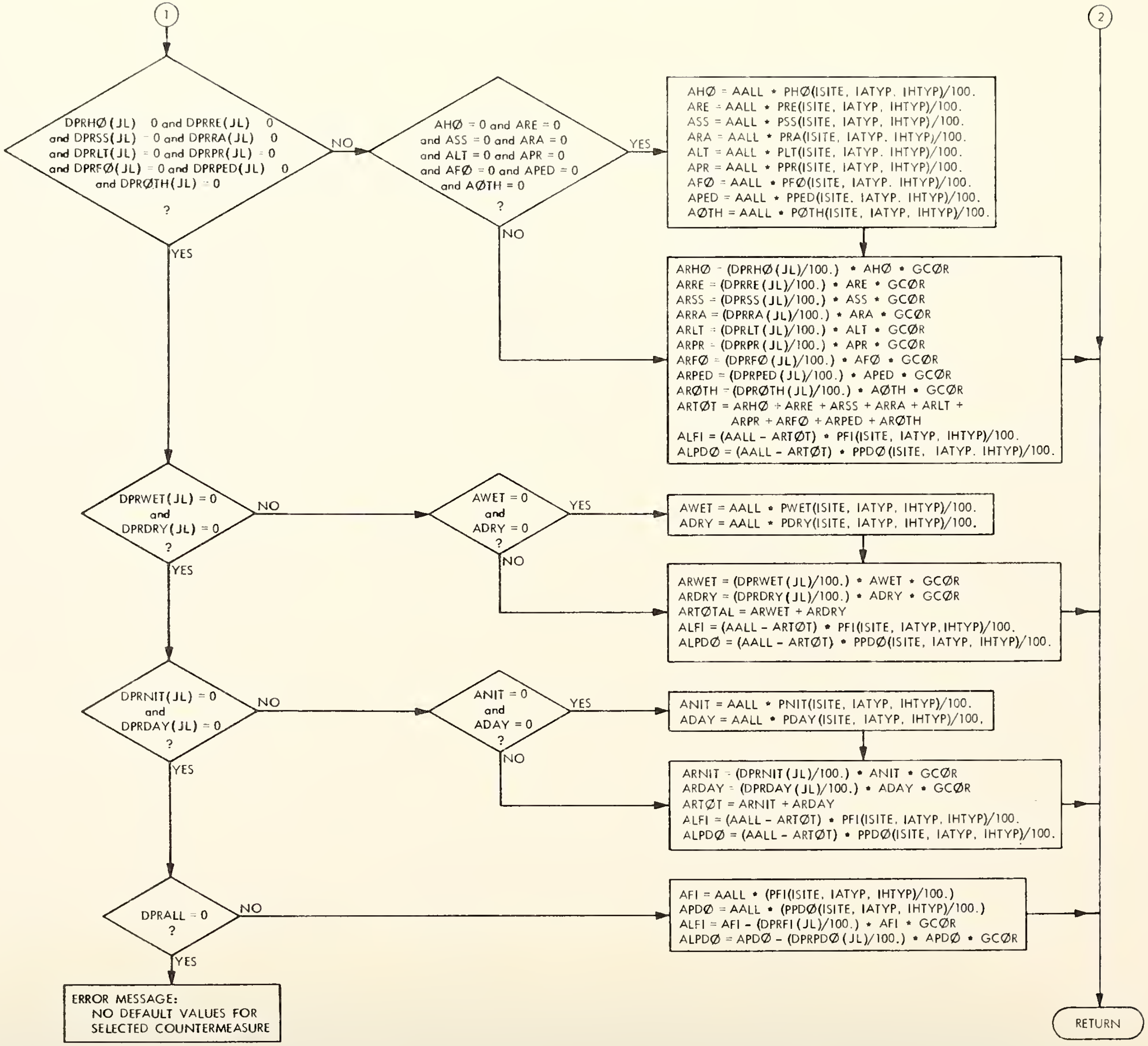


Figure 39 (concluded)

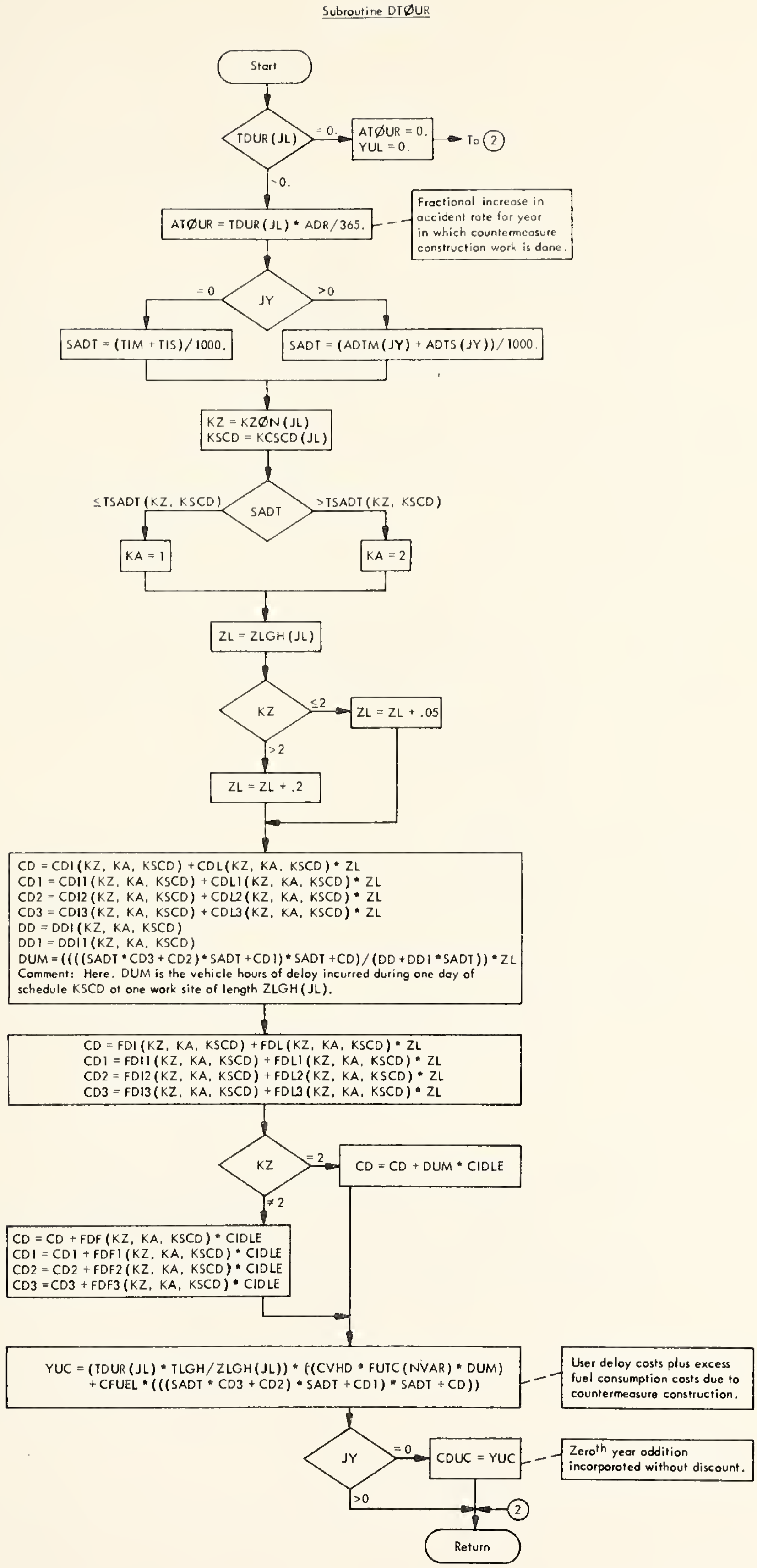
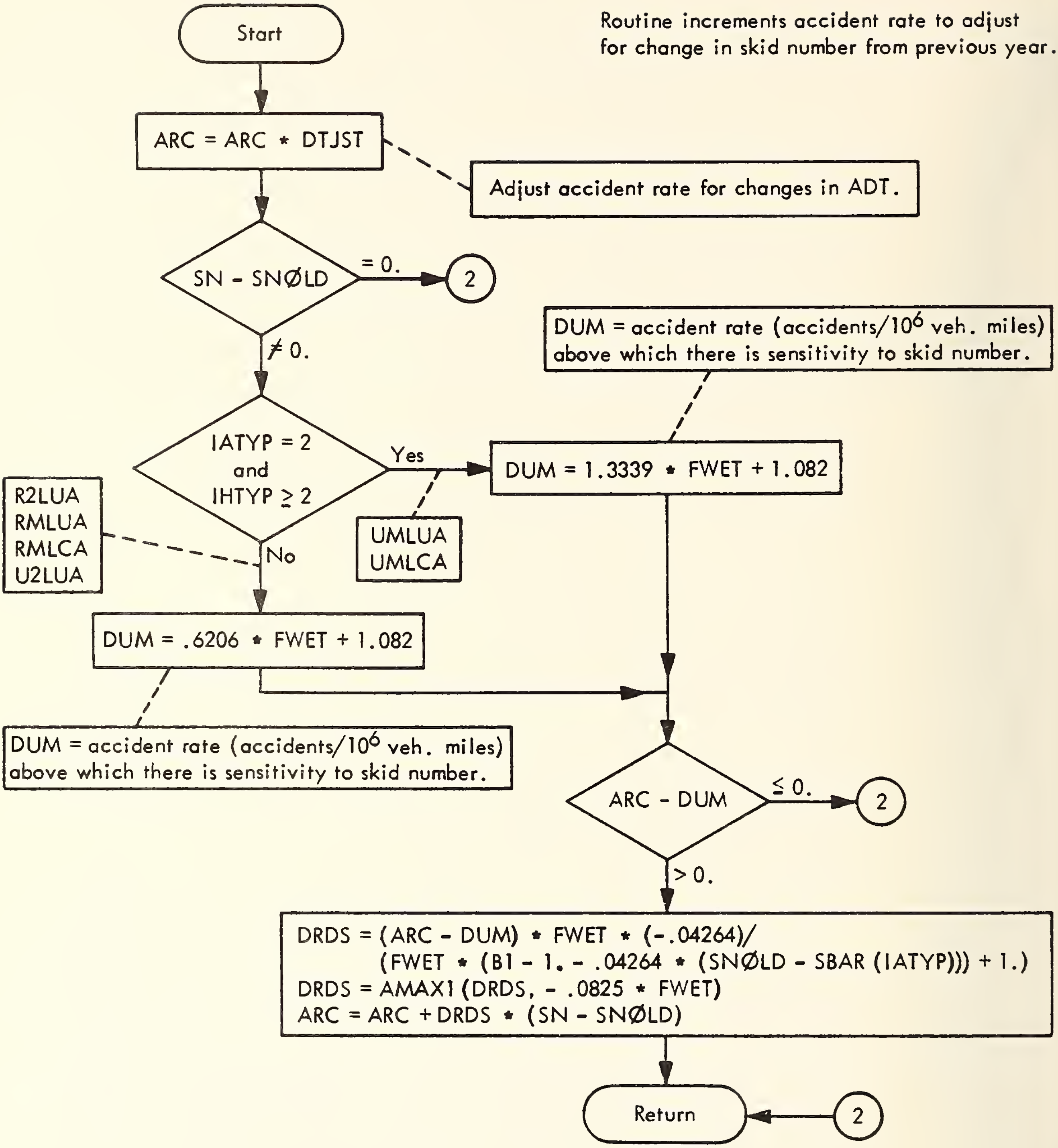


Figure 40 - Subroutine DTØUR Flow Diagram



Routine increments accident rate to adjust for change in skid number from previous year.

Figure 41 - Subroutine SNADJ Flow Diagram

Subroutine CALCST

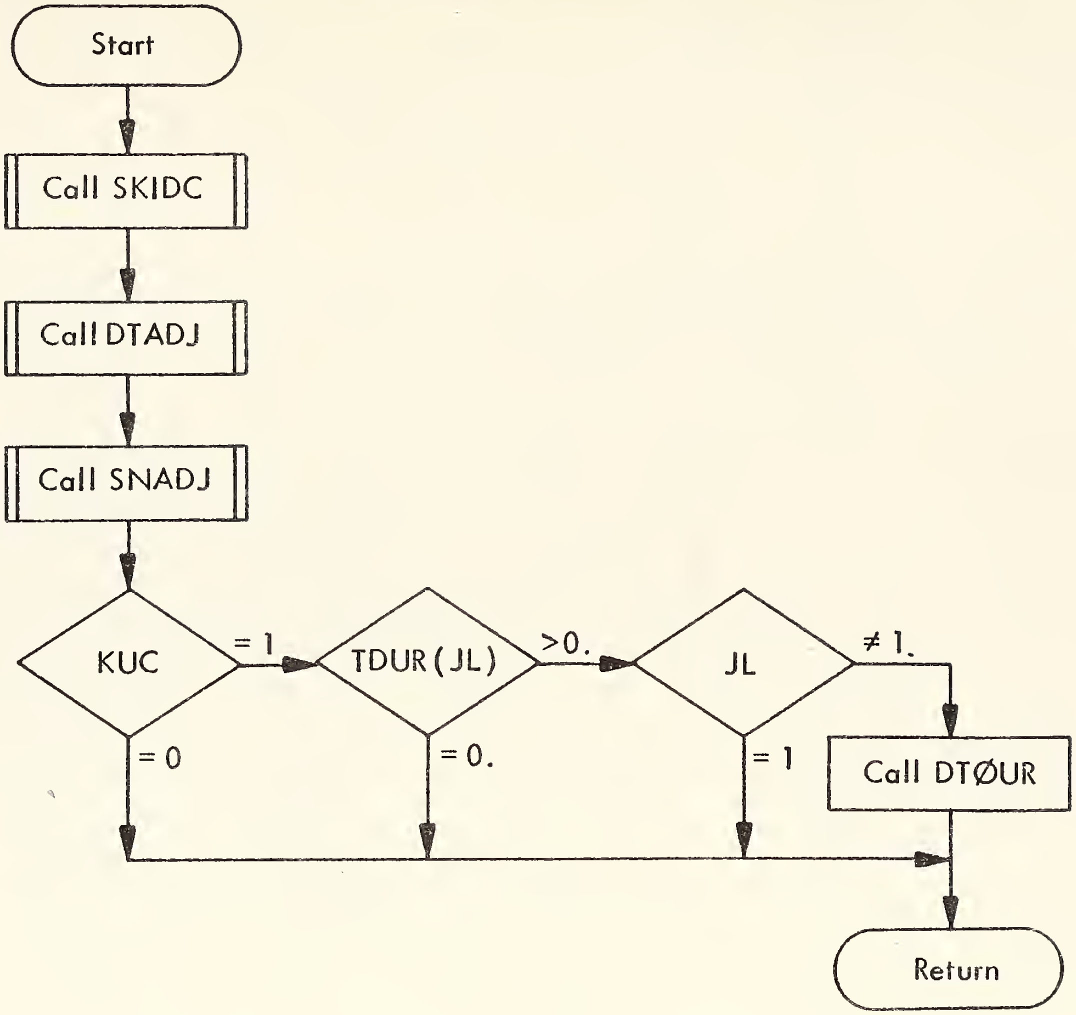


Figure 42 - Subroutine CALCST Flow Diagram

Subroutine SKIDC
(Skid Number Calculation)

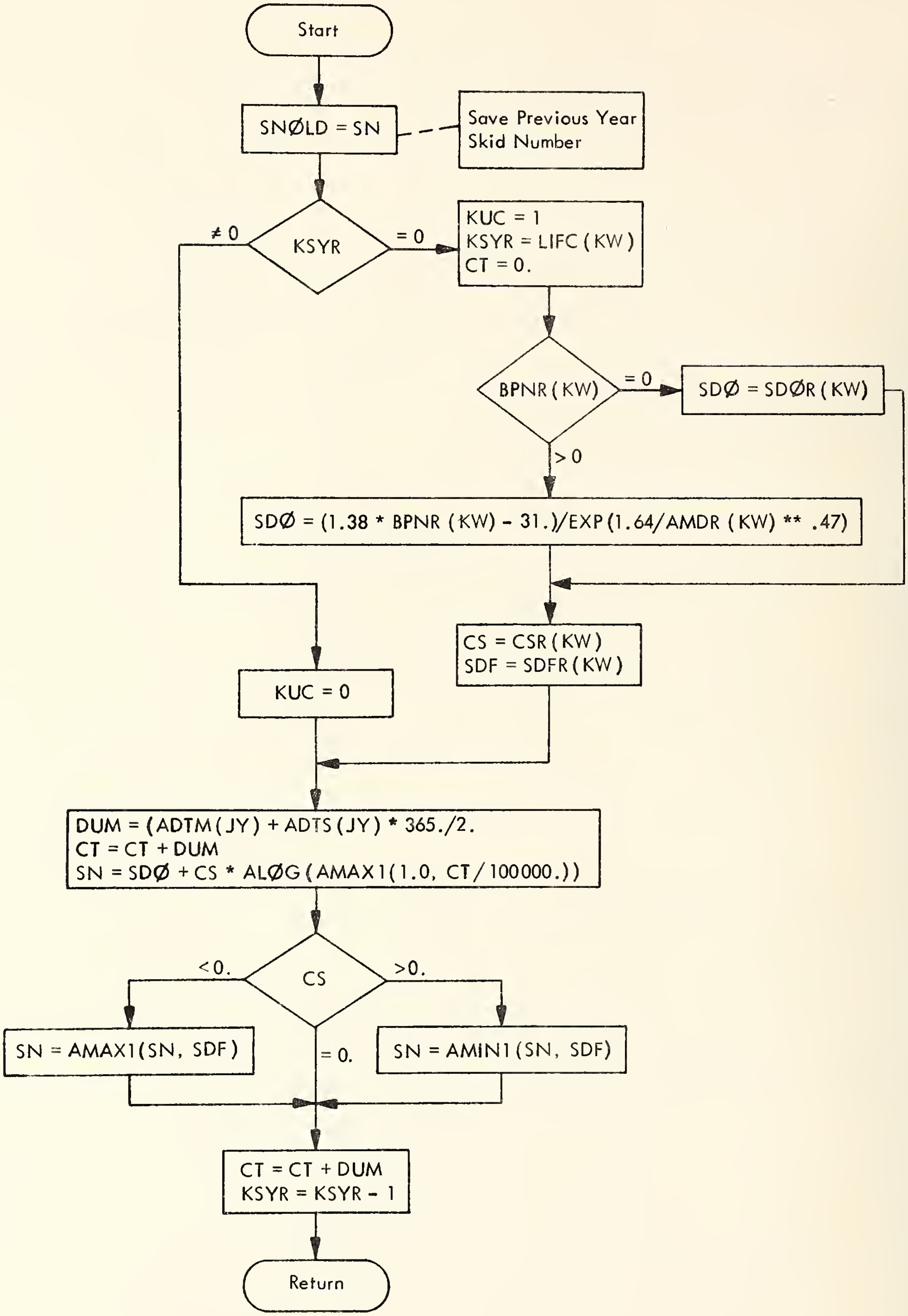


Figure 43 - Subroutine SKIDC Flow Diagram

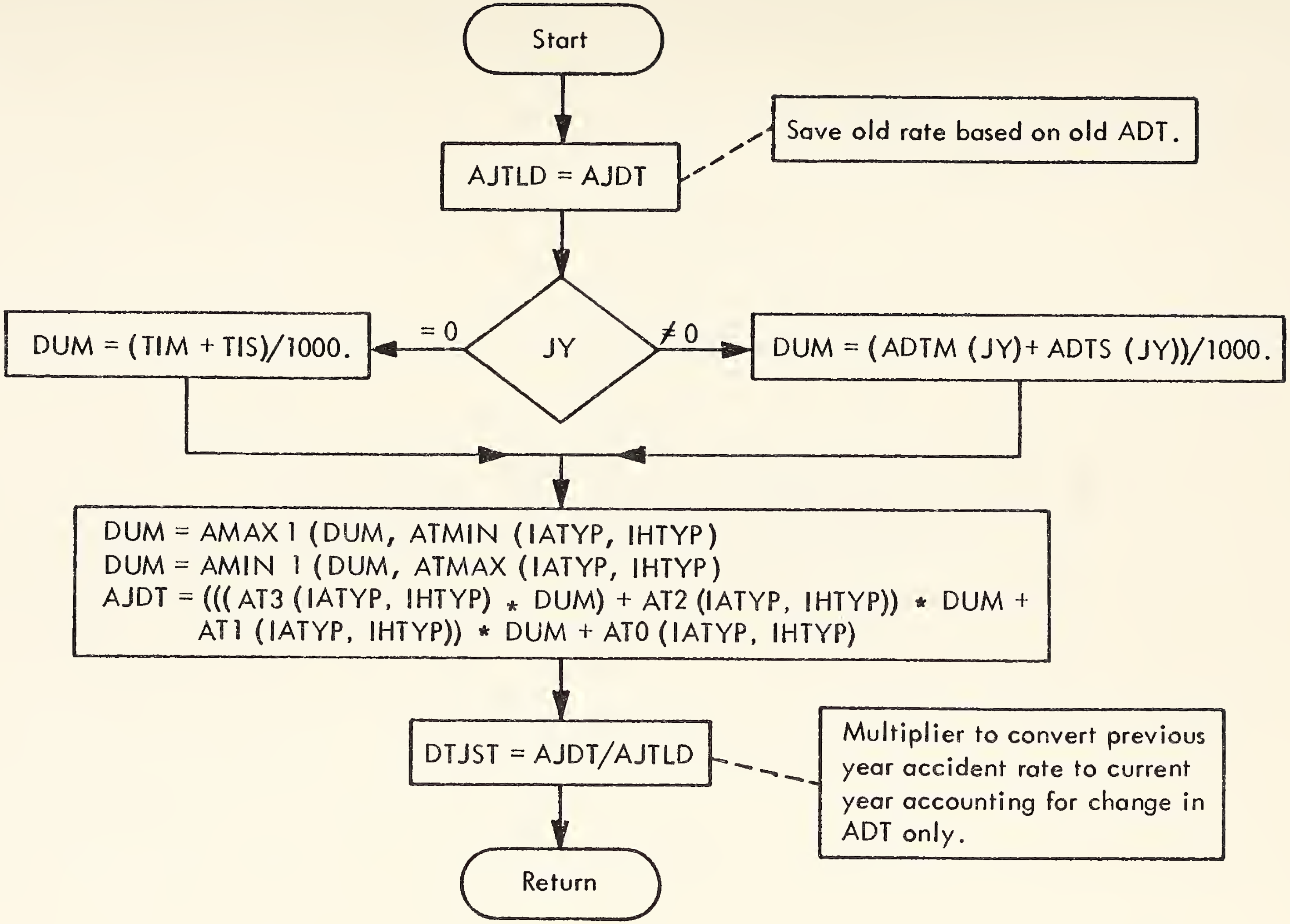


Figure 44 - Subroutine DTADJ Flow Diagram

Subroutine ACCØST

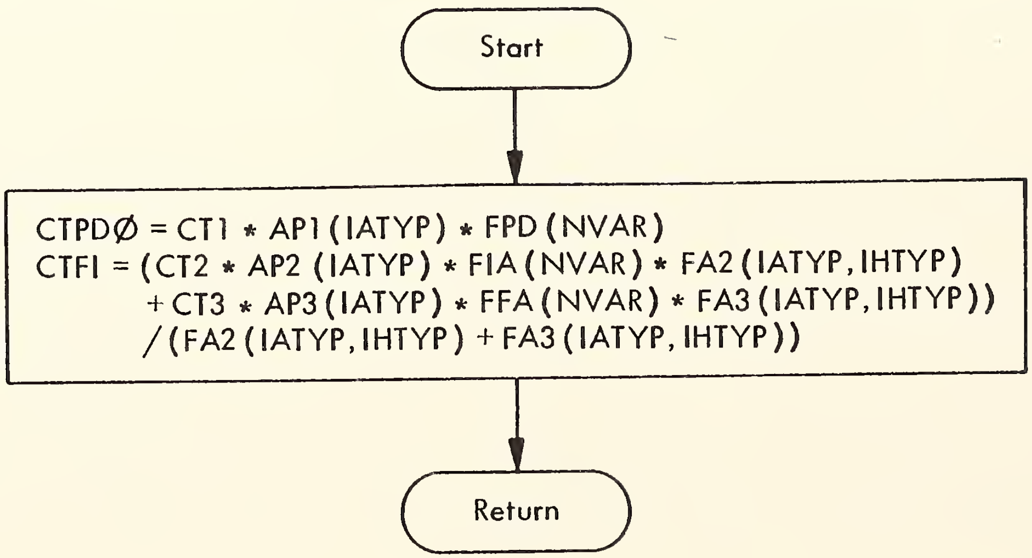


Figure 45 - Subroutine ACCØST Flow Diagram

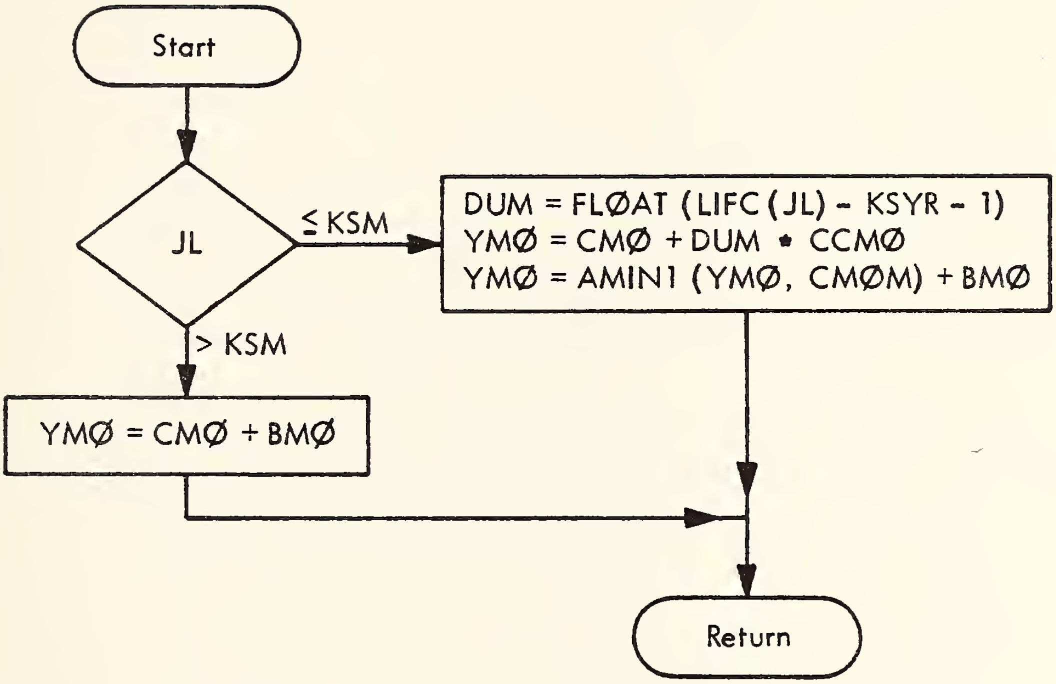


Figure 46 - Subroutine YRMØ Flow Diagram

Subroutine YRAC

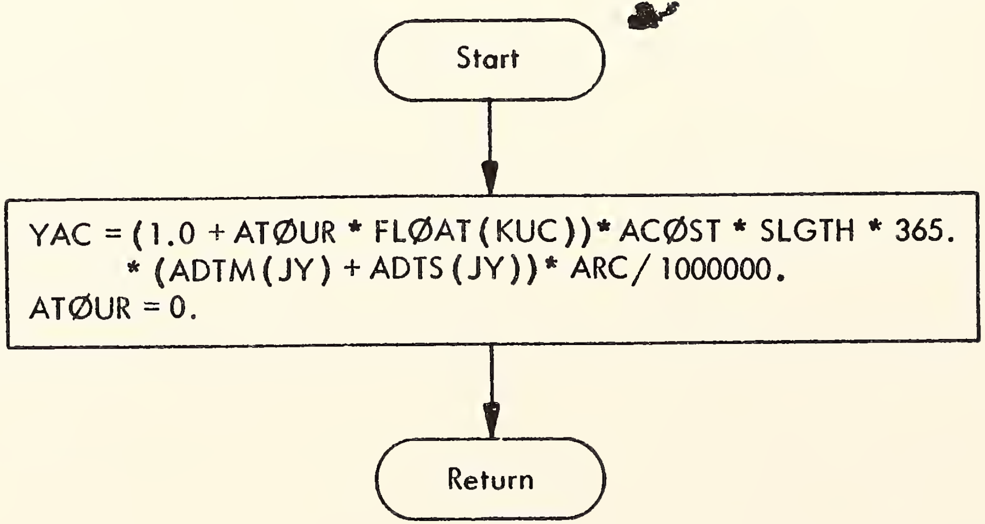


Figure 47 - Subroutine YRAC Flow Diagram

Subroutine DCØSTS

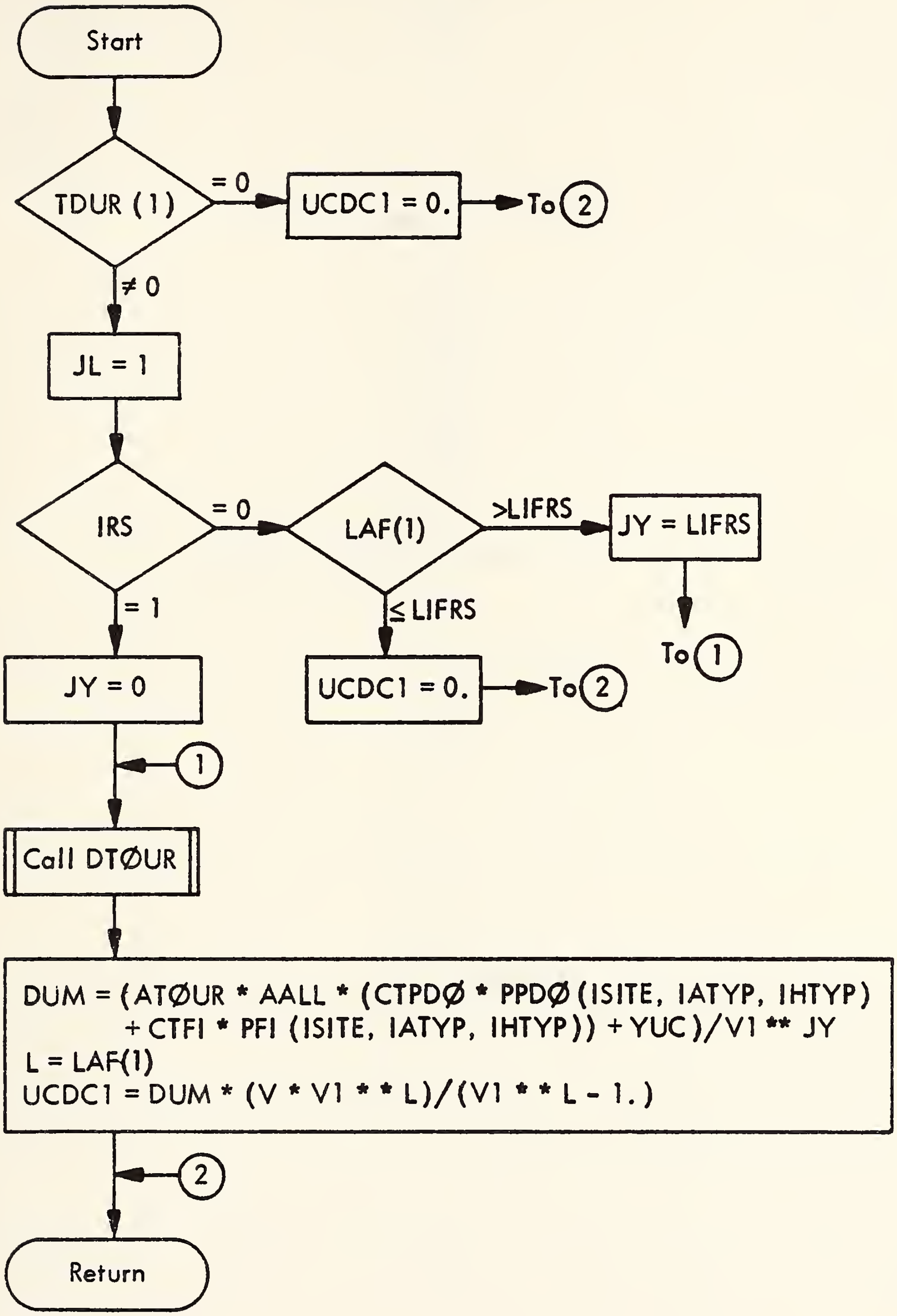


Figure 48 - Subroutine DCØSTS Flow Diagram

APPENDIX F

SUBR0UTINE HIERARCHY

Routine Name	Calls	Is Called By
ACC0ST	--	BCMAIN
ADT	--	BCMAIN
ALIFE	--	BCMAIN
BCMAIN	ACC0ST	--
(main program)	ADT	
	ALIFE	
	EACC	
	EFEAS	
	EXIT	
	FCAPW	
	PFRM	
	PREP1	
	REED	
	SIG (dummy routine)	
	SIG0 (dummy routine)	
	SIGT (dummy routine)	
B0C	C0STS	EFEAS
CALCST	DTADJ	C0STS
	DT0UR	
	SKIDC	
	SNADJ	
C0RRT	--	SETCST
	CALCST	B0C
	SETCST	
	YRAC	
	YRM0	
	YRUC	
DC0STS	DT0UR	BCMAIN
DTADJ	--	CALCST
	--	SETCST
DT0UR	--	CALCST
		DC0STS
		SETCST
EACC	--	BCMAIN
EFEAS	B0C	BCMAIN
EXIT	--	BCMAIN
FCAPW	--	BCMAIN
GREDU	--	SETCST

Routine Name	Calls	Is Called By
PFRM	B0C SEQ	BCMAIN
PREP1	--	BCMAIN
PREP2	--	BCMAIN
REED	--	BCMAIN
SEQ	--	PFRM
SETCST	C0RRT DTADJ DT0UR GREDU DTADJ DT0UR	C0STS
SKIDC	--	CALCST
SKIDI	--	SETCST
SNADJ	--	CALCST SETCST
YRAC	--	C0STS
YRMO	--	C0STS
YRUC (dummy routine)	--	C0STS

APPENDIX G

SYMBOL NAMES AND DEFINITIONS

This appendix provides a description of symbol names used in the computer flow diagrams. A code, presented in Table 28, has been employed to describe some aspects of the symbols.

TABLE 28

CODE DEFINITIONS FOR SYMBOLS

Code No.	Definition
1	Input, mandatory.
2.XX	Input, conditionally mandatory. (Conditions are described in note number XX).
3	Input, optional.
4	Input from system files.
5	Internal to program.
6	Output
7	For potential logic that could be added in the future.

Table 29 presents the symbol names, the code numbers, the estimated dimensions, and the definitions.

TABLE 29

SYMBOL NAMES AND DEFINITIONS

Symbol Name	Code	[Estimated Dimension]	Definition
AALL	1		Total number of yearly accidents at analysis site prior to countermeasure implementation.
ABPN	5		Unsubscripted form of BPNR( ) used in SKIDI.
ACØST	5		Average cost per accident for the severity distribution after initial countermeasure effects.
ACMAØ(IATYP, IHTYP)	4	[2,3]	Average annual maintenance and operating costs per mile in area type IATYP on highway type IHTYP.
ADAY	3		Total number of yearly daytime accidents at analysis site prior to countermeasure implementation.
ADR	4		Factor for increase in accident rate during countermeasure construction.
ADRY	3		Total number of yearly accidents under dry pavement conditions prior to countermeasure implementation.
ADTM( )	2.01	[20]	ADT of major facility in ( )th year.
ADTS( )	2.01	[20]	ADT of secondary facility in ( )th year.
AFI	3		Total number of yearly fatal and injury accidents at analysis site prior to countermeasure implementation.
AFØ	3		Total number of yearly fixed object accidents at analysis site prior to countermeasure implementation.
AHØ	3		Total number of yearly head-on accidents at analysis site prior to countermeasure implementation.
AJDT	5		Accident rate based exclusively on ADT (used to form DTJST).
ALFI	5		Total number of fatal and injury accidents remaining in zeroth year after countermeasure implementation.
ALPDØ	5		Total number of property-damage-only accidents remaining in zeroth year after countermeasure implementation.
ALT	3		Total number of yearly left turn accidents at analysis site prior to countermeasure implementation.
AMDR( )	3	[180)	Mean texture depth (milli-in.) immediately after wear in of surface for countermeasure ( ).
AMD	5		Unsubscripted form of AMDR( ) used in SKIDI.
AMDYØ	2.15		Mean texture depth (milli-in.) for current pavement surface prior to planned changes, if any.
AMØ( )	6	[3]	Average annual maintenance and operating costs (undiscounted) over years 1 through IA.
ANIT	3		Total number of yearly nighttime accidents at analysis site prior to countermeasure implementation.
AØTH	3		Total number of yearly accidents at analysis site prior to countermeasure implementation that do not fall into one of the other 8 accident type categories.

TABLE 29 (Continued)

Symbol Name	Code	[Estimated Dimension]	Definition
AP1(IATYP)	4	[2]	Average number of vehicles per property-damage-only accident.
AP2(IATYP)	4	[2]	Average number of injuries per injury accident.
AP3(IATYP)	4	[2]	Average number of fatalities per fatal accident.
APDØ	3		Total number of yearly property-damage-only accidents at analysis site prior to countermeasure implementation.
APED	3		Total number of yearly pedestrian accidents at analysis site prior to countermeasure implementation.
APR	3		Total number of yearly parking-related accidents at analysis site prior to countermeasure implementation.
APREC	3		Average annual precipitation (inches).
ARA	3		Total number of yearly right-angle accidents at analysis site prior to countermeasure implementation.
ARC	5		Accident rate (accidents/MVM) for year being processed.
ARE	3		Total number of yearly rear-end accidents at analysis site prior to countermeasure implementation.
ASS	3		Total number of yearly side-swipe accidents at analysis site prior to countermeasure implementation.
ATØUR	5		Fraction increase in yearly accident rate due to construction activity.
AWET	3		Total number of yearly wet-pavement accidents at analysis site prior to countermeasure implementaion.
BCR(KM)	6	[180]	Benefit/cost ratio for countermeasure KM.
BIG	5-6		Largest number that can be printed in the format for BCR(KM).
BMØ	5		Basic average annual maintenance and operating costs for site = TLGH*ACAMØ (IATYP, IHTYP).
BPNR( )	3	[180]	British Portable tester number developed immediately after wear in of surface for countermeasure( ).
BPNYØ	2.15		British Portable tester number for current pavement surface prior to planned changes, if any.
CAPC(KM)	4	[180]	Standard capital outlay per unit of countermeasure KM; from data files.
CAPFW(KM)	4	[180]	Fraction of time pavements were wet at sites where countermeasures in the literature were evaluated.
CCAS	7		Factor which multiplies (accident costs eliminated) in expression for SIGT. Default value zero; nonzero can be input. (For use in subroutine SIGØ; not incorporated in present model.)

TABLE 29 (Continued)

Symbol Name	Code	[Estimated Dimension]	Definition
CCMA0(KM)	4	[180]	Annual rate of change of yearly maintenance and operating costs per unit of countermeasure KM. Time is measured from emplacement of the countermeasure, usually used only for KM ≤ KSM.
CDAC	5		Present worth of accident costs for years 1 through IA with countermeasure KM.
CDF	5		Final and constant value of skid number.
CDFR(KM)	4	[180]	Value of CDF for countermeasure KM installed, for KM ≤ KSM.
CDI(KZ, KA, KSCD)	4	[6, 2, 5]	Factor used in calculation of user delays at construction sites.
CDI1(KZ, KA, KSCD)	4	[6, 2, 5]	Factor used in calculation of user delays at construction sites.
CDI2(KZ, KA, KSCD)	4	[6, 2, 5]	Factor used in calculation of user delays at construction sites.
CDI3(KZ, KA, KSCD)	4	[6, 2, 5]	Factor used in calculation of user delays at construction sites.
CDL(KZ, KA, KSCD)	4	[6, 2, 5]	Factor used in calculation of user delays at construction sites.
CDL1(KZ, KA, KSCD)	4	[6, 2, 5]	Factor used in calculation of user delays at construction sites.
CDL2(KZ, KA, KSCD)	4	[6, 2, 5]	Factor used in calculation of user delays at construction sites.
CDL3(KZ, KA, KSCD)	4	[6, 2, 5]	Factor used in calculation of user delays at construction sites.
CDM0	5		Present worth of maintenance and operating costs for years 1 through IA with countermeasure KM.
CDUC	5		Present worth of user costs for years 1 through IA with countermeasure KM.
CFAS	7		Factor which multiplies (fraction of accident costs eliminated) in expression for SIGT.
CFUEL	4		Cost per gallon of fuel.
CIDLE	4		Average fuel consumption (gal/veh-hr) at idle.
CMA0(KM)	4	[180]	For KM > KSM: adjustment to average annual maintenance and operating costs for countermeasure KM. (In this case, CMA0(KM) is normally > 0.)

TABLE 29 (Continued)

Symbol Name	Code	Estimated Dimension	Definition
			For KM KSM: a portion of the adjustment to annual maintenance and operating costs per unit of countermeasure KM. (In this case, CMAØ is normally 0.)
CMAØM(KM)	4	[180]	Upper bound on CMAO(KM) + JY*CCMAØ(KM).
CMØ	5		Constant component of annual maintenance and operating costs, for UN( ) units of countermeasure.
CMØM	5		Current value of UN(KM)*CMAØM(KM).
CØL(KM)	5	[180]	Capital outlay for project with countermeasure KM.
CØLD( )	6	[3]	Initial outlay: (1) = base, (2) = challenger, (3) = challenger-base.
CR(KM)	4	[180]	Cost (per unit) for recovery of capital items in countermeasure KM to employ in added service.
CRF	5		Capital recovery factor. $[i(1+i)^n]/[(1+i)^n - 1]$ where i = interest rate, n = years.
CS	5		Coefficient for in $(CT/10^5)$ term in equation for skid number.
CSR(KM)	4	[180]	Stored value of CS to be used when recycling KM.
CT	5		Cumulative traffic since surface modification.
CT^1	4		Cost of property-damage-only accident per involved vehicle.
CT^2	4		Cost per injury.
CT^3	4		Cost per fatality.
CTFI	5		Average cost of combined fatal and injury accidents including effect of weight factors.
CTPDØ	5		Cost of a property-damage-only accident including weight factor.
CUMMØ	5		Accumulator for undiscounted annual maintenance and operating costs.
CVHD	4		Cost per vehicle-hour of delay.
DDI(KZ, KA, KSCD)	4	[6,2,5]	Factor used in calculation of user delays at construction sites.
DDI^1(KZ, KA, KSCD)	4	[6,2,5]	Factor used in calculation of user delays at contruction sites.
DF	5		Discount factor for year JY.

TABLE 29 (Continued)

Symbol Name	Code	[Estimated Dimension]	Definition
DPRALL(KM)	4	[180]	Default value of percent reduction in all accidents due to countermeasure KM.
DPRDAY(KM)	4	[180]	Default value of percent reduction in daytime accidents due to countermeasure KM.
DPRDRY(KM)	4	[180]	Default value of percent reduction in dry-pavement accidents due to countermeasure KM.
DPRFI(KM)	4	[180]	Default value of percent reduction in fatal and injury accidents due to countermeasure KM.
DPRFØ(KM)	4	[180]	Default value of percent reduction in fixed-object accidents due to countermeasure KM.
DPRHØ(KM)	4	[180]	Default value of percent reduction in head-on accidents due to countermeasure KM.
DPRLT(KM)	4	[180]	Default value of percent reduction in left-turn accidents due to countermeasure KM.
DPRNIT(KM)	4	[180]	Default value of percent reduction in nighttime accidents due to countermeasure KM.
DPRØTH(KM)	4	[180]	Default value of percent reduction in accidents that do not fall into one of the other 8 categories due to countermeasure KM.
DPRPDØ(KM)	4	[180]	Default value of percent reduction in property-damage-only accidents due to countermeasure KM.
DPRPED(KM)	4	[180]	Default value of percent reduction in pedestrian accidents due to countermeasure KM.
DPRPR(KM)	4	[180]	Default value of percent reduction in parking-related accidents due to countermeasure KM.
DPRRA(KM)	4	[180]	Default value of percent reduction in right-angle accidents due to countermeasure KM.
DPRRE(KM)	4	[180]	Default value of percent reduction in rear-end accidents due to countermeasure KM.
DPRSS(KM)	4	[180]	Default value of percent reduction in side-swipe accidents due to countermeasure KM.
DPRWET(KM)	4	[180]	Default value of percent reduction in wet-pavement accidents due to countermeasure KM.
DTJST	5		Factor used to adjust previous year accident rate to current year rate accounting for effect of ADT change only.
DUM	5		Dummy variable used in several subroutines (can be in CØMMØN).

TABLE 29 (Continued)

Symbol Name	Code	[Estimated Dimension]	Definition
EUAAC(JK)	6	[3]	Equivalent uniform annual accident costs over years 1 through IA.
EUACC(KM)	6	[180]	Equivalent uniform annual capital cost for required units of countermeasure KM.
EUAM0(JK)	6	[3]	Equivalent uniform annual maintenance and operating costs over years 1 through IA.
EUAUC(JK)	6	[3]	Equivalent uniform annual user costs over years 1 through IA.
FAAC	7		Minimum equivalent uniform annual accident costs. (For use in subroutine SIG0; not incorporated in present model.)
FCR	5		Fraction of their applied capital worth which can be recovered at time of resurfacing or rebuilding (the fractional part of TRL(KM) for countermeasure being evaluated).
FCW(KM)	5-2.02	[180]	Final capital worth per unit of countermeasure KM after IAF(KM) years.
FDI(KZ, KA, KSCD)	4	[6, 2, 5]	Factor used in calculation of user delays at construction sites.
FDI1(KZ, KA, KSCD)	4	[6, 2, 5]	Factor used in calculation of user delays at construction sites.
FDI2(KZ, KA, KSCD)	4	[6, 2, 5]	Factor used in calculation of user delays at construction sites.
FDI3(KZ, KA, KSCD)	4	[6, 2, 5]	Factor used in calculation of user delays at construction sites.
FDL(KZ, KA, KSCD)	4	[6, 2, 5]	Factor used in calculation of user delays at construction sites.
FDL1(KZ, KA, KSCD)	4	[6, 2, 5]	Factor used in calculation of user delays at construction sites.
FDL2(KZ, KA, KSCD)	4	[6, 2, 5]	Factor used in calculation of user delays at construction sites.
FDL3(KZ, KA, KSCD)	4	[6, 2, 5]	Factor used in calculation of user delays at construction sites.
FDF(KZ, KA, KSCD)	4	[6, 2, 5]	Factor used in calculation of user delays at construction sites.
FDF1(KZ, KA, KSCD)	4	[6, 2, 5]	Factor used in calculation of user delays at construction sites.
FDF2(KZ, KA, KSCD)	4	[6, 2, 5]	Factor used in calculation of user delays at construction sites.
FDF3(KZ, KA, KSCD)	4	[6, 2, 5]	Factor used in calculation of user delays at construction sites.

TABLE 29 (Continued)

Symbol Name	Code	[Estimated Dimension]	Definition
FFA(NVAR)	3	[6]	Factor for fatal accident costs in NVARth variation of case in progress. Default = 1.0.
FIA(NVAR)	3	[6]	Factor for injury accident costs in NVARth variation of case in progress. Default = 1.0.
FPD(NVAR)	3	[6]	Factor for prop. damage accident costs in NVARth variation of case in progress. Default = 1.0.
FUTC(NVAR)	3	[6]	Factor for user time costs in NVARth variation of case in progress. Default = 1.0.
FWET	1		Fraction of time with wet pavement at site being analyzed.
GCØR	5		Correction factor for accident reduction due to geometric and traffic control countermeasures.
IA	5-6		Interval of analysis (years).
IATYP	1		Subscript for area type; 1 = rural, 2 = urban.
IHTYP	1		Subscript for highway type; 1 = two-lane, uncontrolled access, 2 = multilane, uncontrolled access, 3 = multilane, controlled access.
ILST( )	5	[180]	Subscripts of countermeasures found to be economically feasible. Sequence ILST(1) to ILST(NCEPT) arranged in order of increasing EUACC(KM).
IØK	5-6		Normally = 0. Set to nonzero values in cost routines when insufficient data are provided.
IRS	1		Code for prior decision to resurface the analysis site; 1 = prior decision to resurface immediately, 0 = no prior decision to resurface immediately.
ISITE	1		Subscript for site type; 1 = highway section, 2 = non-intersection location, 3 = intersection.
ISTAR	1		Code for region within state.
ISTAT	1		Code for state.
IYR	5		Subscript for year of analysis period, used in subroutine ADT.
JATYP(KM)	4	[180]	Area type for which countermeasure KM is appropriate; 0 = all area types, otherwise see IATYP.

TABLE 29 (Continued)

Symbol Name	Code	[Estimated Dimension]	Definition
JHTYP(KM)	4	[180]	Highway type for which countermeasure KM is appropriate; 0 = all highway types, otherwise see IHTYP.
JK	5		Subscript associated with line of output; 1 = base, 2 = challenger, 3 = difference.
JL	5		Subscript of countermeasure being processed in subroutine CØSTS (must be in CØMMØN).
JPER(NVAR)	3	[6]	Control for logic selecting period of analysis. 1 for short period; 2 for long period. Default = 2.
JSITE(KM)	4	[180]	Site type for which countermeasure KM is appropriate; 0 = all site types, otherwise see ISITE.
KB	5		Subscript of countermeasure employed as base condition.
KC	5		Subscript of countermeasure employed as challenger.
KCSCD(JL)	2.03	[180]	Code for construction schedule for countermeasure JL.
KLST( )	5	[180]	The subscripts, (KM), of countermeasures to be evaluated for application at site analyzed, KLST(1) = 1, the "as is" or "as planned" condition. Countermeasure subscripts are KLST(2) to KLST(MLST).
KM	1		Subscript of countermeasure or right-of-way data.
KM2	4		Lower limit of subscripts for countermeasures that may require right-of-way.
KM3	4		Upper limit of subscripts for countermeasures that may require right-of-way.
KMAX	4		Maximum subscript for countermeasures. Reserved for use in subroutine SIGØ; not incorporated in present model.
KSM	4		Upper limit of subscripts reserved for countermeasures involving surface modification.
KSTAR	1		Code for region within state as read from input.
KSTAT	1		Code for state as read from input.
KSYR	5		Number of years until surface modification.
KUC	5		Code for user costs due to construction; = 1 for years when incurred, = 0 for years when not incurred.

TABLE 29 (Continued)

Symbol Name	Code	[Estimated Dimension]	Definition
KW	5		Subscript for surface to be used in calculating skid number (must be in CØMMØN). Can be KM or KWS.
KWS	2.04		User-supplied subscript ≤ KSM, indicating surface type in place; to be used if countermeasure processed is KM > KSM. Default value = 1.
KZØW(JL)	2.03	[180]	Type of work site configuration used for countermeasure JL.
LAF(KM)	2.05 -3-5-6	[180]	Applied life (years) of countermeasure KM at site analyzed.
LIFC(KM)	4	[180]	Normal life (years) of countermeasure KM.
LIFF	1		Remaining life of facility (years).
LIFRB	1		Years until scheduled or estimated rebuilding at site analyzed.
LIFRS	1		Years until scheduled or estimated resurfacing at site analyzed.
LTR(KM)	5	[180]	Code for reason life of countermeasure KM will be terminated at site analyzed. Equals 1 for remaining life of facility, 2 for rebuilding in future year, 3 for resurfacing in future year, 4 for normal life of countermeasure.
MLST	5		Largest subscript for KLST( ) employed in analysis in progress.
MVAR	5		Maximum value of NVAR for analysis in progress. Default = 1.
MXYR	3		Longest period of analysis (years). Default value = 20.
NCEPT	5		Number of countermeasures found economically feasible.
NVAR	5		Subscript for FPD( ), FIA( ), FFA( ), FUTC( ), and JPER( ).
PDAY(ISITE, IATYP, IHTYP)	4	[3, 2, 3]	Percent of all accidents which are daytime accidents.
PDRY(ISITE, IATYP, IHTYP)	4	[3, 2, 3]	Percent of all accidents which are dry-pavement accidents.
PFI(ISITE, IATYP, IHTYP)	4	[3, 2, 3]	Percent of all accidents which are fatal or injury accidents.
PFØ(ISITE, IATYP, IHTYP)	4	[3, 2, 3]	Percent of all accidents which are fixed-object accidents.

TABLE 29 (Continued)

Symbol Name	Code	[Estimated Dimension]	Definition
PHØ(ISITE, IATYP, IHTYP)	4	[3, 2, 3]	Percent of all accidents which are head-on accidents.
PLT(ISITE, IATYP, IHTYP)	4	[3, 2, 3]	Percent of all accidents which are left-turn accidents.
PNIT(ISITE, IATYP, IHTYP)	4	[3, 2, 3]	Percent of all accidents which are nighttime accidents.
PØTH(ISITE, IATYP, IHTYP)	4	[3, 2, 3]	Percent of all accidents which are not in one of the other 8 categories of accidents.
PPDØ(ISITE, IATYP, IHTYP)	4	[3, 2, 3]	Percent of all accidents which are property-damage-only accidents.
PPED(ISITE, IATYP, IHTYP)	4	[3, 2, 3]	Percent of all accidents which are pedestrian accidents.
PPR(ISITE, IATYP, IHTYP)	4	[3, 2, 3]	Percent of all accidents which are parking-related accidents.
PRA(ISITE, IATYP, IHTYP)	4	[3, 2, 3]	Percent of all accidents which are right-angle accidents.
PRE(ISITE, IATYP, IHTYP)	4	[3, 2, 3]	Percent of all accidents which are rear-end accidents.
PSS(ISITE, IATYP, IHTYP)	4	[3, 2, 3]	Percent of all accidents which are side-swipe accidents.
PWET(ISITE, IATYP, IHTYP)	4	[3, 2, 3]	Percent of all accidents which are wet-pavement accidents.
PRALL(KM)	2.06	[180]	User-specified value of percent reduction in all accidents due to countermeasure KM.
PRDAY(KM)	2.06	[180]	User-specified value of percent reduction in daytime accidents due to countermeasure KM.
PRDRY(KM)	2.06	[180]	User-specified value of percent reduction in dry-pavement accidents due to countermeasure KM.
PRFI(KM)	2.06	[180]	User-specified value of percent reduction in fatal and injury accidents due to countermeasure KM.
PRFØ(KM)	2.06	[180]	User-specified value of percent reduction in fixed-object accidents due to countermeasure KM.
PRHØ(KM)	2.06	[180]	User-specified value of percent reduction in head-on accidents due to countermeasure KM.
PRLT(KM)	2.06	[180]	User-specified value of percent reduction in left-turn accidents due to countermeasure KM.
PRNIT(KM)	2.06	[180]	User-specified value of percent reduction in nighttime accidents due to countermeasure KM.

TABLE 29 (Continued)

Symbol Name	Code	[Estimated Dimension]	Definition
PROTH(KM)	2.06	[180]	User-specified value of percent reduction in accidents that do not fall into one of the other 8 categories of accidents due to countermeasure KM.
PRPDO(KM)	2.06	[180]	User-specified value of percent reduction in property-damage-only accidents due to countermeasure KM.
PRPED(KM)	2.06	[180]	User-specified value of percent reduction in pedestrian accidents due to countermeasure KM.
PRPR(KM)	2.06	[180]	User-specified value of percent reduction in parking-related accidents due to countermeasure KM.
PRRA(KM)	2.06	[180]	User-specified value of percent reduction in right-angle accidents due to countermeasure KM.
PRRE(KM)	2.06	[180]	User-specified value of percent reduction in rear-end accidents due to countermeasure KM.
PRSS(KM)	2.06	[180]	User-specified value of percent reduction in side-swipe accidents due to countermeasure KM.
PRWET(KM)	2.06	[180]	User-specified value of percent reduction in wet-pavement accidents due to countermeasure KM.
RALLO	5		Initial accident rate, used internally.
RN	6		Equivalent uniform annual net return.
SADT	5		Sum of ADT for major and secondary facilities, divided by 1000.
SALV(KM)	4	[180]	Net salvage value per unit of countermeasure KM at end of normal service life.
SBAR(IATYP)	4	[2]	Average skid number for area type IATYP; SBAR(1) = 46.0, and SBAR(2) = 39.7.
SCAPC(KM)	2.07	[180]	Nonstandard capital outlay per unit of countermeasure KM; supplied by program user in input.
SCMAO(KM)	3	[180]	User-supplied value of average annual maintenance and operating costs that supercedes the standard file value for CMAO(KM).
SDF	5		Final value of skid number; upper or lower bound depending on sign of CS.
SDFR(KM)	4	[180]	Stored value of SDF for countermeasure KM.
SDO	5		Constant in equation for skid number; the value of the skid number immediately after implementation of countermeasure if KM ≤ KSM.

TABLE 29 (Continued)

Symbol Name	Code	[Estimated Dimension]	Definition
SDØR(KM)	4	[180]	Stored value of SDØ to be used when recycling KM.
SIGT	7		Test value for potential of significant reduction of accident costs; = CFAS *(fraction of accident costs eliminated) + CCAS *(accident costs eliminated) - 1.0. Potentially significant reduction requires SIGT > 0.
SLGTH	5		Site length in miles. From by user for route sections. Site pseudo-length generated internally for intersections and nonintersection point locations.
SN	5		Skid number, subject to change with time.
SMAØM(KM)	3	[180]	User-supplied value superceding CMAØM(KM).
SNØLD	5		Skid number in previous year.
SNYØ	1		Skid number in zeroth year prior to planned surface changes, if any.
SSMAØ(KM)	3		User-supplied value superceding CCMAØ(KM).
TDUR(JL)	2.03	[180]	Time in days that construction of countermeasure JL is in in a work site length ZLGH(JL).
TIM	1		ADT for major facility in zeroth year.
TIS	2.08		ADT for secondary facility in zeroth year.
TLGH	1		Total length of analysis site, in miles.
TMGC	2.09		Percent compounded growth rate of ADT of major facility.
TMGL	2.10		Percent linear growth rate of ADT of major facility. Normally only one of the two variables, TMGC and TMGL, should be nonzero.
TRL(KM)	4	[180]	Code for vulnerability of countermeasure KM to resurfacing and rebuilding. Digit part = 1 when capital items are disturbed by rebuilding but not by resurfacing. Digit part = 2 when capital items are disturbed by resurfacing and have net salvage value only at time of rebuilding. Fractional part is the fraction of applied then capital value which can be recovered exclusive of the cost of removal.

TABLE 29 (Concluded)

Symbol Name	Code	Estimated Dimension	Definition
TSGC	2.11		Percent compounded growth rate of ADT of secondary facility.
TSGL	2.12		Percent linear growth rate of ADT of secondary facility. Normally, only one of the two variables, TSGC and TSGL, should be nonzero.
UCC(JK)	6	[3]	Equivalent uniform annual capital cost for project.
UCDCI	5		Present worth of user costs due to construction activity to implement prior decisions and future plans.
UN(KM)	2.13	[180]	Number of units of countermeasure KM required at site analyzed.
V	3		Interest rate (decimal percent) used in analysis. Equal to VS unless supplied by program user.
V^1	5		(V + 1.0).
VS	4		Interest rate (decimal percent) from data files for state and state region.
YAC	5		Accident costs during JY^{th} year for site.
YEARS	5		Number of years since countermeasure placement.
YM0	5		Maintenance and operating costs during JY^{th} year for analysis site.
YUC	5		User costs during JY^{th} year for site.
ZLGH(JL)	2.14	[180]	Length of work site for countermeasure JL.

NOTES FOR TABLE 29

No. of Note	Note
01	ADTM(JY) and ADTS(JY) JY = 1, 20 constitute one of three ways to input ADT projections. One of options must be used. ADTS( ) required only at an intersection site. Other options are compound growth and linear growth; see TMGC, TMGL, TSGC and TSGL.
02	FCW(KM) is mandatory input for a countermeasure (KM) for which the user has supplied LAF(KM) as input. FCW(KM + K2) is mandatory input for countermeasure KM that requires non-zero right-of-way costs. Otherwise, FCW(KM) is normally calculated in program.
03	Input is mandatory for a countermeasure, JL, that requires a work site for construction.
04	KWS should be provided as input if the "as is" or "as planned" surface is not the standard type with subscript 1. Otherwise program will use skid and cost characteristics of subscript one.
05	LAF(KM + K2) is mandatory input for the life or amortization period of the right-of-way with non-zero costs for countermeasure KM. Otherwise, LAF(KM) is optional input if the program user wishes to override the value calculated internally by the computer program. Note that FCW(KW) is also mandatory if LAF(KM) is supplied in input.
06	Input is mandatory for at least of these when program user specifies a geometric or traffic control countermeasure that is not part of the system file. In this case, KM will be a subscript that is unused in files.
07	SCAPC(KM) is optional for any countermeasure where CAPC(KM) is available from system files and user overrides with SCAPC(KM). SCAPC(KM) is mandatory input for unfiled countermeasure KM with characteristics supplied by user. SCAPC(KM + K2) is mandatory for non-zero capital cost per unit of right-of-way for countermeasure KM.
08	TIS is required as input if site is an intersection.

NOTES FOR TABLE 29 (Concluded)

No. of Note	Note
09	TMGC is mandatory input if the projected ADT are based on a compound growth.
10	TMGL is mandatory input if the projected ADT are based on a linear growth.
11	TSGC is mandatory if site is an intersection (ISITE = 3) and projected ADT are based on a compound growth.
12	TSGL is mandatory input if site is an intersection (ISITE = 3) and projected ADT are based on a linear growth.
13	UN(KM) are mandatory input for all countermeasures (KM) to be evaluated at the site under analysis. In addition, input for UN(KM + K2) may be required for right-of-way units associated with KM. And finally, UN(1) or UN(KSW) may be required to quantify the costs of pavement alterations set by prior decision for the zeroth year or for anticipated future schedules.
14	ZLGH(JL) are mandatory for those countermeasures (JL) that have been specified for evaluation in input and also require construction TDUR(JL) > 0. Also, either ZLGH(1) or ZLGH(KSW) will be required depending on site conditions in the zeroth year. Failure to supply a needed ZLGH( ) will cause the associated construction site length to have a minimum value.
15	AMDY0 must be supplied as input if BPNY0 is supplied. (They will be used only if SNY0 is not input.)

APPENDIX H

CONTROLLING SKIDDING BY INFLUENCING DRIVER BEHAVIOR

One way to control skidding is to regulate the behavior of the driver so that, in effect, demands for skid resistance of a highway surface are decreased. Regulation has several aspects such as getting the driver to reduce speed when the surface is wet, getting him to drive less erratically and thus decrease the possibility of positioning the vehicle so that a skid is likely, and teaching him to recognize potential skidding conditions and/or what to do when a skid once begins. Unfortunately, no studies presently exist dealing directly with skidding from the driver's standpoint, so the closest that we can come is to consider general factors that control (or do not control) driver behavior. The following is a discussion of this topic, with emphasis placed on speed control because speed is perhaps the single most important factor in the genesis of a skid. Six specific subject areas are covered: training, static signing, dynamic signing, signing relevancy, delineation, and vehicular factors. Law enforcement techniques are not considered. A conclusion section follows the six areas.

1. Training: The possibility of training drivers to make appropriate control actions when a skid begins has undoubtedly been considered since driving began, but surprisingly little seems to have been done to implement the idea. Forbes[27/] stressing the importance of such training, commented that skidding is a dominant factor in accidents and recommended that skid instruction be given in driver education courses. Some progress was made in the next few years. Later, an article in the American Journal of Insurance (1969) discussed skid schools and various facilities including simulators that existed for training drivers to handle panic situations like skids. The article concluded that such facilities offered the possibility of "crisis conditioning" under safe circumstances.

The extent to which skid-control training facilities exist today cannot be known without a formal survey. Hanscom[36/] lists the Liberty Mutual Insurance Company's Skid School, a school that trains race car drivers to take curves at the highest possible of levels without skidding, and the Penn State University Skid Simulator. There are more, of course, but only a formal survey can tell how many.

A literature search failed to yield any studies dealing with the effectiveness of skid training. It is assumed that it is, or at least could be, effective but data must be obtained to make sure. A straightforward study in which one group of driver education students receives skid training while a similar group does not could easily be made, with the two groups being compared for the types and severity of accidents that they have for several years after the instruction. From these data the cost-effectiveness of such training could be calculated.

Finally, it should be noted that the literature has nothing to say about the possibility of training drivers to recognize potential skidding conditions. It would seem that this possibility should be explored; perhaps drivers, especially inexperienced ones, could profit greatly from such training.

2. Static signing: Static signs are signs unenhanced by lights or any other attention-getting device. Studies will be considered in three categories: identification frequencies, effectiveness, and parameters affecting identification.

a. Identification frequencies: Hakkinen[33/] placed test signs ahead of a curve, then stopped drivers and asked them to tell what they remembered of the signs after passing them. Only 28% recalled a general warning sign but 62% recalled it when supplementary information was added. Seventy-eight percent recalled a 70 km speed limit sign while 80% recalled a 50 km limit sign indicating that fairly large differences in allowable speed did not affect perception. Blackburn, Glauz, Kobett, and Sharp[9/] reported that 65% of drivers passing an ice warning sign on a bridge recalled seeing it. In a recent study, Summala and Näathanen[65/] had subjects drive over a 257 km course with instructions to name all traffic signs they saw along the route. They reported about 97% of the signs, and the authors concluded that earlier experimental results indicating that drivers see relatively few signs probably reflect a lack of motivation. This seems to be reasonable; undoubtedly, if drivers searched diligently for information they would find more than they normally do and would probably act on it to a greater extent. The problem, of course, is to find some means of providing the motiviation.

b. Effectiveness: Several early studies reported that static signing had little influence on speed (Ottini,[52/] Rowan and Keese,[60/] Brackett,[12/] Ballinger[6/]). Later studies both support and dispute these findings. Hammer[34/] found that standard curve warning signs did not reduce accidents by themselves but that they did when advisory speed signs were added. Accidents considered were the nighttime, single vehicles, running-off-road type. The City of Wayne, Michigan, installed overhead lane-use control signs on a one-way street ahead of a particular intersection (Hoffman[38/]). Total accidents at that intersection went down 44% in 1 year while those due to turning from the wrong lane went down 58%. It was claimed that this saved the city $47,900 for the year. Culp and Dilhoff[18/] placed static signs reading "watch for ice on bridge" at 24 different locations and stated that this reduced accidents. However, Stewart and Sequeira[64/] reported that static ice or frost warning signs were ineffective; these authors believe that this was so because motorists see these signs so frequently that they cease to pay attention to them.

In still another study, Ritchie[55] found that subjects drove faster and produced more lateral acceleration in curves when a curve and speed advisory sign were present than when they were not. He also reported that drivers exceeded advisories of 15 to 35 mph but not those of 45 to 50. Recently, Rutley[61] reported that speeds of vehicles in curves approached those of the advised maximum advisory speeds displayed on signs; in some cases vehicles reduced speed and in some cases they increased it. Rutley also reported that these speed advisory signs, placed at 150 curves in three counties in England, reduced accidents by 44% in one county but did not affect accidents in the other two. The author pointed out that the advised speeds were developed under carefully controlled conditions and were those that yielded the maximum speed but still gave comfortable radial accelerations to drivers and passengers.

Evidence for the effectiveness of static signs is thus conflicting. Nevertheless, it should be pointed out that most of the negative evidence comes from earlier work, and that perhaps some of the later work avoided some of the mistakes made earlier and thus tended to yield positive results. There is a suggestion in those studies yielding positive results that the circumstances in which signs are used may be a critical factor in determining effectiveness. Ritchie[56] reported that speeds increased when 15 to 35 mph advisories were encountered but did not change when 45 to 50 mph advisories were encountered while Rutley[6] found that speeds increased in some cases and decreased in others. Rutley also found dramatic accident reduction in one county but none in two others. Unfortunately, these data do not suggest what factors promote effectiveness although the work discussed in the immediately following subsection and the two sections after that offer some ideas. We conclude here that static signing can be effective in regulating speed but is not necessarily so.

c. <u>Parameters affecting identification</u>: In a laboratory study whose purpose was to determine the effectiveness of lane drop signs, Burg[14] showed movies and still pictures of signs. He found that they preferred a 4 x 8 ft rectangular sign over several 40 x 40 in. diamond-shaped signs and that the preferred message of several was "lane end" in a line above "merge left." As variables, shape is confounded here by size so it is impossible to conclude anything about preferences for either variable, but we can conclude that type of message is important. In a study previously cited, Hakkinen[33] also found that road familiarity did not affect motorists' noticing an ordinary sign but did when supplementary information was added in that they saw the sign more then. Ferguson and Cook[25] used questionnaires to evaluate drivers' awareness of sign color and shape. They found that drivers do not pay much attention to color except that they recognize red, white, and yellow the most often. They also found that shape and message type were the most important variables determining sign effectiveness.

Eklund[23] performed a laboratory study to determine what factors influence drivers' recall of signs. Important variables were found to be brightness, brightness contrast, simplicity, difference from other signs, and frequency of appearance; as would be expected, increasing amounts of all of these variables enhanced recall. Cameron[16] had subjects classify signs by their function into one of four categories. The dependent variable was classification time. Among other findings he reported that signs with symbolic messages were superior to signs with verbal messages. Backlund[5] questioned drivers about various aspects of a sign they had just passed. He found that those familiar with the road gave the largest number of correct answers, sign violators gave the least number of correct answers, and sparse traffic decreased drivers' awareness of the sign. To determine how signal visibility affects accidents, Kassan and Crowder[45] improved the visibility of signals at 68 intersections in Los Angeles. This treatment at a cost of less than $5,000/intersection reduced the most commonly occurring types of accidents.

To summarize these findings, some factors that influence driver's sign perceptions are message content and type (with evidence that symbolic messages are superior to verbal ones); frequency of occurrence of the sign and the amount by which it differs from other signs; simplicity of the sign and its brightness, brightness contrast, and visibility; and familiarity with the road on the part of the driver. It is noteworthy that many of these factors are the same as those manipulated by advertisers such as message content, intellectual level, frequency, uniqueness, and intensity. There are undoubtedly other important factors and it would be prudent to identify them.

3. Dynamic signing: This section reviews studies in which the information to be imparted by static signs is enhanced by lights or any other attention-getting device. In one of the earliest of these, Brackett[11] investigated the value of adding a yellow flashing beacon to existing signing, and found that this had little or no effect in reducing vehicle speeds under various conditions. Blackburn et al.[9] reported that vehicle speeds were about 7 mph or 11% lower when a sign reading "icy bridge ahead" plus a flashing signal was present 1/4 mile upstream of a bridge than when neither sign nor flashing signal was present. In a study testing how adding a traffic signal to a rural crossroad affected approaching vehicles' speeds, Bleyl[10] found that the signal caused drivers to approach the intersection more cautiously than they did before under several conditions.

In a discussion of problems of driving in fog, Schwab[62] stated that directional types of fixed-lighting systems have proved to be effective in guiding drivers in fog at night. He also stated that variable message signs that warn of fog and indicate desirable speeds are the best. Hanscom[36] studied drivers' responses to two types of skidding hazard, wet pavement and icy bridges. He found that signing these hazards without flashing lights was not effective (in contradiction to the earlier findings of Culp and Dilhoff[18]) but that adding warning lights reduced speeds. Speed reductions in the approach to the bridge averaged about 3 mph during the day and 5 mph during the night. The most effective sign pattern was one in which a sign appeared ahead of the bridge as well as on it. A questionnaire elicited the information that hazard cues were roadway curvature and superelevation, behavior of other vehicles, appearance of the pavement's surface, ambient conditions, known site accident history, and the skid warning sign (only four out of 305 respondents or 1% said this last was their cue of a potential skid hazard).

In a study of the effects of five signing configurations warning drivers of an upcoming school zone, Rosenbaum, Young, Byington, and Basham[59] found that dynamic signing was superior to static signing in getting motorists to reduce speeds in the school zone and that, in general, increasing the amount of information decreased speeds to a greater extent. The most effective condition was one in which five signs were used including one in which lights flashed on a sign saying "speed violation when flashing" when the speed limit was exceeded. In this condition the amount of speed reduction of automobiles from 2,600 to 200 ft of the school was 20.6 mph or about 50% whereas in the static signing condition the reduction in the same interval was only 1.6 mph or about 5%.

In summary, dynamic signing is superior to static signing and adding attention-getters to static signs improves their effectiveness. Work that has been done to investigate dynamic signing has not been systematic; usually some kind of attention-getter such as a flashing light is added to an existing static sign and the effects on traffic flow studied. Systematic work involving such variables as sign location, message type, and signal intensity would seem to be in order. Finally, a note of caution regarding the use of novel signs, especially dynamic ones, should be made. If they are used too frequently, drivers can be expected to ignore them because their attention-getting value will diminish; adaptation such as this is well-established in behavioral science work.

4. Signing relevancy: This title refers to the fact that stimuli designed to regulate drivers' behavior must be relevant to their needs and capabilities in order to be effective. In 1949, Wiley observed that traffic ignores posted speed limits and that people drive not by the speedometer but by prevailing traffic, roadway, and environmental conditions. Jackman[42] studied several reflectorized and nonreflectorized signs reading "slow" and "stop" and found that the "slow" sign was ignored if put where it was not warranted. In a study comparing reactions to signs of different kinds, Howard[40] concluded that the perception of signs increases sharply the more "reasonably" the sign relates to roadway conditions. Brackett[12] stated that signing had no effect on speed and that people drive according to highway geometrics and Bezkorovainy[8] reiterated this when he said that speeds in curves were not related to posted advisory speeds but to curve geometrics.

Ballinger[6] studied the operation of two ice warning systems and observed that signing "inconsistent with prevailing conditions" was generally disregarded by motorists. In commenting on motorists' attitudes, Williams and Van Der Nest[71] said that "instead of accepting the warnings, commands, or information presented by road signs, the road user prefers to draw his own conclusions from his observations of the road, and to act on them in preference to the signs." A similar view was espoused by Forbes, et al. (quoted in Hanscom[36]), who stated that motorists were most likely to respond to warning signs in the presence of perceived hazards. Blackburn, et al.[9] also found that drivers responded better to ice warning signs when the perceived hazard was present, as did Hanscom.[36]

Some of these investigators are clearly pessimistic about the ability of signs to regulate driver behavior. However, the definite belief of several others is that one important factor determining whether or not drivers pay attention to signs is their relevancy to that to which they refer. If drivers think a sign's information is relevant or meaningful, they will heed it; if not they will ignore it. The principle is clear: sign information (and undoubtedly any other regulatory stimuli) must accurately reflect whatever it is that is referred to, and it must be realistic in terms of the capabilities and limitations of the driving population or it will be useless and a waste of money.

5. Delineation: As used here, delineation techniques include: lane lines, edge lines, and other lines or colors painted or laid on pavement, raised pavement markers, rumble strips, and reflectors installed on the pavement or mounted on posts at the side of the road. With regard to speed control, several studies have concerned themselves with edge lines. Most have yielded negative results despite a report by Williston[72] that they increased speeds in general and one by the Arizona Department

of Highways[4] that they increased speeds at night. Taragin[67] reported no effects nor did Powers and Michael.[54] A study by the Missouri State Highway Commission[50] also reported no effects and, more recently, a study by David[22] found that implementing delineation treatments such as adding a freshly painted center line, raised pavement markers, and post markers had no effects.

Evidence exists that more dramatic delineation treatments have an effect on speed. Anderson and Pederson[2] put 12-in. wide reflectorized colored edge lines, colored post delineators, and colored guide signs on entrances and exits of a freeway cloverleaf interchange. Entrances and exits were blue or yellow. Behavioral effects were found on the exits only: blue exits had higher exit speeds and later points of exit than normal, while yellow exits had the reverse effects. Only 25% of the drivers were aware of the color treatments. In a study involving colored pavement, Gwynn and Selfort[32] paved a freeway exit ramp red and found they daytime speeds were lower after the ramp was colored but that there was no effect at night.

Transverse white lines have been painted across driving lanes at exponentially decreasing distances apart to try to get drivers to reduce speed faster than normal as they approach situations such as intersections or toll booths. They are reported to be effective although no American studies attesting to this turned up in the literature search upon which this section of the report is based. However, a recent report concerning English roads by Rutley[61] supports the idea. In his study, Rutley painted these kinds of lines at the ends of lengths of high-speed four-lane highways at eight sites. Each site had 90 yellow lines 0.6 m wide covering the last 0.4 km before the intersection was reached. Initial spacing was 7 m and this reduced exponentially to 2 m. Final results of the effectiveness of the lines are not known, but Rutley reported a 10% reduction in average speed during the day and a 19% reduction at night at one site and a 16% reduction in the 85th percentile and 8% reduction in the average speeds at another.

Although speed is the single most important factor in skids, the amount of lateral movement of a vehicle in its lane is also important; other things being equal a vehicle that moves laterally more than another will have a higher probability of getting into a skid situation. There is some evidence that adding edge lines decreases variability of lateral movement. Conley and Roth[17] found that adding edge lines plus white post delineators decreased erratic vehicle movements when used with color coding for ramps. Czar and Jacobs[19] reported that edge lines decreased lateral placement variability while David[22] showed that freshly painted center lines also reduced it.

Thus, adding edge lines apparently does not affect vehicles' speeds but more dramatic delineation treatments can affect speed at least in certain specific cases. Of special interest is the finding that transverse lines painted on pavement can reduce speed. The theory behind this is that speed cues come from perceived motion of objects in the peripheral field, and that causing these cues to appear to stream past at an abnormally fast rate should increase apparent speed and thus lead drivers to reduce actual speed. There is no reason why this technique could not be used in many different situations such as curves, downhill slopes, traffic circles, and T-intersections. It is also possible that exponential patterns could be painted at the edges or center of driving lanes or arranged in posts or other markers beside the highway. The patterns could be placed on the pavement as a kind of rumble strip; the cues here would not be visual but should affect drivers the same way since slowing down is associated with pavement segments being felt farther and farther apart.

6. Instrumentation: This topic deals with speed regulation through stimuli provided by instruments on the vehicle. Thus far only the speedometer has been considered. In one study, Ritchie, Howard, Myers, and Nataraj[56/] showed that subjects who drive without a speedometer drove faster than subjects who drove with one. Rutley[61/] tested subjects with a head-up display (HUD) of speed. When a HUD is used, information is projected onto the windshield of a vehicle through collimated light so that the image is focused at infinity. The operator sees the image at his farthest fixation point with the result that he does not have to change focus when looking into the distance as he does when flying or driving. Rutley found that 85th percentile speeds were reduced in curves by 5 to 10% depending on the vehicles' speed, and that drivers came closer to driving at advisory speeds in curves with the HUD than without it.

7. Conclusions:

a. Static signs can help control drivers' behavior in certain situations but apparently not in others. The reasons for this are complex; many factors undoubtedly contribute. A few such as frequency, message content, and relevancy have been found to be important. Of these, the single most important is probably relevancy; if drivers think a sign's information does not conform accurately and realistically with real-world conditions, they ignore it. Motivation is another factor; drivers motivated to look for signs see nearly all whereas they miss many if not motivated.

The suggestion that emerges from this is that each sign must be precisely tailored to fit each situation it is placed in. This is done now to a certain extent of course, but the reviewed studies showed that driver behavior was not affected in many cases, indicating that something was done incorrectly. Also, the fact that drivers see strikingly small percentages of signs in many cases indicates incorrect fits. It should be relatively easy to develop signing criteria from behavioral work, e.g., questionnaires would certainly provide much useful data and on-the-spot evaluation by panels of drivers would do the same.

b. Dyanmic signing is more effective than static signing. Studies indicate speed reductions from 11 to 50% when this kind of presentation is used. One reason for success undoubtedly stems from the fact that in many cases signs are activated under certain specific conditions such as ice or fog. This increases the relevancy of the sign and thus drivers pay more attention to it. Another reason is that dynamic signs have more attention-getting value if designed with a reasonable amount of care.

c. Delineation can help regulate speed and variability. Speeds at the end of four-lane roads can be reduced at least 10% in the daytime and 19% at night using transverse lines, and by unspecified amounts on freeway exit and entrance ramps through use of elaborate combinations of colors, edge lines, and post delineations. It would be interesting to test dynamic delineation techniques for their ability to help regulate behavior. If results similar to those obtained from signing are found, dynamic delineation should provide much more effective control than static delineation.

d. A vehicle's instruments can also influence speed and hence skid potential. With a HUD, speed in curves can be reduced by at least 5 to 10%. It is difficult to think of head-up display as a practical technique because it is difficult to do, at least at the present, and thus would not be economically feasible. It is possible, of course, that research and mass production could eventually reduce costs to an acceptable level.

e. The literature reviewed here shows that most driver behavior studies have tried to determine how behavior is affected at special sites like intersections by using specific stimuli like signs. Very little work exists that deals with factors that affect behavior generally, over long periods of time. The exception to the latter is work that seeks to determine the effects of changes such as marking the edges of roads or displaying vehicle information in novel ways such as on the windshield. Unfortunately, this work has either yielded negative results or positive results difficult to do anything about.

If the skid reduction problem is thought of as a specific one, i.e., one in which it is desired to reduce speeds at special sites, the data are encouraging. Speeds can be reduced, especially with dynamic signing, and it should be very possible to do it under wet highway or other conditions that increase skid potential. Whether or not the speed reduction that can be achieved is sufficient to lower the skid potential to a safe level is another matter, one that ultimately will have to be subjected to experimental test.

If the skid reduction problem is thought of as a general one, i.e., one in which it would be desirable to reduce speeds of vehicles over long stretches of road, the data are not so encouraging. In this case the simplest procedure would be to train drivers to recognize potential skidding conditions and what to do if they do skid (this would apply as well to the specific case just discussed). If more direct control is desired, new techniques will have to be developed. These might range from series of signs placed along the road that are activated when the road is wet enough to decrease its skid resistance below a critical value and that display various warning messages when activated, to delineation treatments similarly activated. It might also be possible to build vehicles so that they seem to go faster when the road is wet; it is a fairly common experience to slow down when large puddles are encountered suddenly and unexpectedly on a wet highway.

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FEDERALLY COORDINATED PROGRAM OF HIGHWAY RESEARCH AND DEVELOPMENT (FCP)

The Offices of Research and Development of the Federal Highway Administration are responsible for a broad program of research with resources including its own staff, contract programs, and a Federal-Aid program which is conducted by or through the State highway departments and which also finances the National Cooperative Highway Research Program managed by the Transportation Research Board. The Federally Coordinated Program of Highway Research and Development (FCP) is a carefully selected group of projects aimed at urgent, national problems, which concentrates these resources on these problems to obtain timely solutions. Virtually all of the available funds and staff resources are a part of the FCP, together with as much of the Federal-aid research funds of the States and the NCHRP resources as the States agree to devote to these projects.*

FCP Category Descriptions

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Safety R&D addresses problems connected with the responsibilities of the Federal Highway Administration under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

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Maintenance R&D objectives include the development and application of new technology to improve management, to augment the utilization of resources, and to increase operational efficiency and safety in the maintenance of highway facilities.

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